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Relative energy consumption of transport modes in Finland

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AALTO UNIVERSITY SCHOOLS OF TECHNOLOGY PO Box 12100, FI-00076 AALTO http://www.aalto.fi		ABSTRACT OF THE MASTER'S THESIS	
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<p>When comparing the energy efficiency of transport modes the different spatial contexts and the resulting trip characteristics must be taken into account in order to bring about realistic and fair results. The objective of this master thesis is to find out the actual number of consumed energy and generated emissions per passenger on an annual basis using realistic load factors and mode choice scenarios in these different contexts.</p> <p>The results show that especially with modern private vehicles the energy efficiency and fuel consumption for autos is competitive with buses in rural areas where buses carry far less people on board than in urban environment. If, however, the private vehicle driving distances increase radically due to shifting to the more fuel efficient vehicles, the advantages of the reduction of emissions and fuel consumption on a per vehicle basis will be offset quickly.</p> <p>Furthermore, criticism of people as environmentally irresponsible citizens simply because they drive their automobile or other private vehicle is unwarranted. In rural areas, the bus exists not because it is better environmentally but because it fulfills a social need for mobility for those without autos. People who never drive in their home city may actually have the largest carbon footprint of anyone in their neighborhood if they do a large amount of long distance travel. The findings from this study argue for a more holistic and realistic approach to evaluating energy efficiency of particular lifestyles and for designing policy responses.</p>			
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Table of contents

Abstract	
Acknowledgements	
Table of contents	1
1 Introduction	3
1.1 Research issue and the objective of the study	3
1.2 Definition of research	4
2 Travel environments	5
2.1 Spatial contexts	5
2.1.1 Dense urban-, medium and small town travel environments	5
2.1.2 Rural travel environment	7
2.1.3 Long distance travel	11
2.1.4 Very long distance trips abroad	13
3 Transport modes and propulsion	14
3.1 Transport modes included for comparison	14
3.1.1 Private vehicles	14
3.1.2 Pedestrian and bicycle	15
3.1.3 Motorcycle and moped	16
3.1.4 Urban and intercity buses	17
3.1.5 Metro	18
3.1.6 Regional rail in southern Finland	20
3.1.7 Intercity rail	21
3.1.8 Airliners	22
3.2 Propulsion alternatives	23
3.2.1 Gasoline vehicles	23
3.2.2 Diesel vehicles	24
3.2.3 Hybrid vehicles	26
3.2.4 Alternative energy sources	27
4 Trip classification and categorization	28
4.1 Different perspectives	28
4.1.1 Trip purpose	28
4.1.2 Time of travelling	30
4.1.3 One mode or multiple modes	31
4.1.4 Occupancy level and load factors	32
4.1.5 Mode choice scenarios	34
4.2 Earlier research	37
4.3 Forming example trips for mode comparison	39
4.3.1 Very long distance trips	40
4.3.2 Long distance trips	41
4.3.3 Rural trips	42
4.3.4 Small town trips	43
4.3.5 Dense urban trips	44
4.3.6 Commuting between towns and cities	44
4.3.7 Case study	45
5 Analysis and results	47
5.1 Background information for analysis	47
5.1.1 Fuel consumption and emission amounts	47
5.1.2 Passenger capacities of modes	54
5.1.3 Actual load factors	55

5.2	Results	58
5.2.1	Full vehicles	58
5.2.2	Very long distance travelling	60
5.2.3	Long distance travelling	61
5.2.4	Rural travelling	65
5.2.5	Small town trips	69
5.2.6	Commuting to nearby city	70
5.2.7	Dense urban trips	72
5.2.8	Case study	76
5.3	Reasoning of results	79
5.4	Other emissions	80
5.5	Engine cold start	84
6	Future	85
7	Conclusions	88
	References	91

1 Introduction

1.1 Research issue and the objective of the study

Many figures are cited about the relative energy efficiency and environmental responsibility of different transport modes. The subject is commonly brought up in the media and it seems to interest people increasingly. There are many different possible performance indicators used to describe the energy efficiency and greenhouse gas generation of transport modes. Nevertheless the comparisons presented between these different transport modes are often too simplistic and therefore they give unfair results towards some of the compared modes.

In practice the actual real life relative energy efficiency differs on each individual circumstances and it is affected by many different elements. When the objective is to bring about a reliable comparison of energy efficiency and greenhouse gas generation of different transport modes it is important to examine carefully how the comparison should be performed.

The classification and categorization of different journeys based on the trip purpose and the spatial context on which the trip is travelled is very important to take into notice when comparing the energy efficiency of different transport modes. The surroundings and trip purpose for example affect possible mode choice alternatives and therefore only trips with certain similar features should be compared together. Another example of variables that should be very carefully investigated before comparison are the actual load factors likely to be seen in practice on specific transport modes on a particular type of trip. Load factors have a significant effect on the greenhouse gas generation per person when the emissions generated for travelling a certain distance are divided by the passengers of a full vehicle compared to a vehicle which is travelling with only few passengers.

In order to make a scientifically rigorous analysis on the relative energy consumption and greenhouse gas generation of transport modes and to be sure that the results are reliable and presentable for comparison, the foregoing issues must be taken into consideration.

The contribution of this study is to find out which transport mode is environmentally the best alternative in different trip situations, given the current physical layout and population size. The study will also answer the question how should the different trips be categorized in order to handle every transport mode equally and to provide comparable numbers for comparison. The study will also try to demonstrate how the different mode choice scenarios in different environments discard some of the modes as possibilities. In many cases the surrounding environment limits the use of some modes and in other cases there is only one realistic mode available.

1.2 Definition of research

This study includes the most common passenger transportation modes used in Finland. The study includes different road transport modes and rail transport modes including intercity and regional rail and metro. Also air passenger transport is included. The study does not include marine transport. Freight transportation is also not included into this thesis. The transport modes investigated in this thesis are private vehicles, intercity and urban buses, trains and airplanes of different types and the most common propulsion alternatives are included.

The spatial contexts which are included into the thesis are urban passenger transport in dense urban and smaller town environments. Rural area passenger transport is also investigated. Long distance travelling (including long distance trips inside Finnish borders) and very long distance travelling (including trips to Europe and other continents) are investigated as an own trip group. The study focuses mainly in passenger travelling in Finland and only few examples of international long distance trips are included.

2 Travel environments

2.1 *Spatial contexts*

2.1.1 Dense urban-, medium and small town travel environments

Comparing energy efficiencies of different transport modes or calculating the greenhouse gas emissions on a certain route seems to be an easy task. If the subject is investigated more deeply one can find out that the comparison must be done very carefully and the whole travel environment must be studied beforehand. Investigating trips or journeys that an individual travels in his or her everyday life is a complex thing to do. Does a person living in a rural area use more energy for everyday life travelling than a person living in a large city? How should we make a meaningful comparison of the different modes that are there for us to use for a certain trip? These are some of the quite simple sounding questions related to travelling. When observed more carefully, we can find out that getting answers to those questions is not so simple after all.

The classification of different trips individuals travel in their everyday lives is a complex process. There are many ways to categorize trips and there are even more different perspectives to approach the issue. How the categorization should be done is strongly affected by the characteristic which is investigated. When the issue is to compare and examine energy efficiency of different transport modes the comparison must be done separately for different travel environments in order to get results that are not misleading or even unfair towards some modes. Each spatial context, whether it is rural or urban, has its own individual features and effects on travelling. Therefore the trips in which the energy efficiency of different transport modes is investigated must be classified properly.

The spatial context in which a certain trip is travelled is important to be taken into account when comparing transport modes with each other. In different situations the surroundings affect radically attributes such as travel time, average trip length, mode choice and the utilization rate of a certain road or street used (Finnish Transport Agency 2012). In addition the surrounding environment has a notable impact on modal load

factors which depend on population density in the area. The energy efficiency and energy consumption of transport modes are also affected by the surroundings, whether the vehicle can be driven free speed on a highway or it must slow down in a traffic jam in a city (Luttinen et. al. 2005).

When beginning to compare transport modes with each other, first it is important to define in which spatial context are the trip travelled in. When trips are categorized by geographic scope the broad division can be made between urban and intercity travel environments (Vanek et. al. 2008). Categorization between these two large groups is quite broad relative to the investigated subject. Therefore it is necessary to categorize them into smaller groups. The word urban can cover large urban areas, medium sized towns as well as smaller towns. However there are major differences between large city, medium size town and small town travel environments as well as the characteristics in the suburban areas which are surrounding bigger cities (Vanek et. al. 2008).

In addition to the differences in the large city and small town infrastructures is the supply and demand for public transport services. There are less scheduled bus routes available in a small town than in a larger city. Also the variety of different public transportation modes and amount of trips travelled by public transportation varies widely and correlates with the size of the city and the size of the population in the area. For example in a small town the demand for a scheduled bus line that operates between the town center and a nearby town in every half an hour is not profitable to the bus operator due to the lack of customers. The headway between buses can sometimes be hours. Therefore when an individual makes the choice on which mode to use for a certain trip it might be more likely that a small town citizen uses a car than a bus because there is no available bus lines on the moment needed. In a larger city or in the Helsinki metropolitan area bus routes are operated much more frequently. Therefore an individual has a higher likelihood of choosing the bus instead of a car. Another notable difference between small town and larger city environment travel behavior is that in small town environment the average length of bus trips is three times longer compared to the average length of bus trips in a larger city (Finnish Transport Agency 2012). This is because the fact that people in smaller towns live further from the town center than in larger cities where services are closer.

In an urban environment most of the everyday services are at a relatively close range and therefore the average trip lengths are much shorter than in the rural areas where one must travel even tens of kilometers to the nearest grocery store. It is also common that in a rural environment the different shopping trips are joined together to a same trip to avoid travelling the long distances many times per day whereas in an urban environment many independent short trips are common because the services are relatively near (Riikonen 2008).

The traffic congestion varies a lot and depends on the population density and size of the city or town. Traffic jams are mostly common to urban and suburban environment. In order that a traffic jam is developed there must be over a certain amount of vehicles on the road (Luttinen et. al. 2005). Traffic jams occur normally during periods in the morning and afternoon when people are travelling to work and back. High traffic congestion is common in the ring roads and highways leading to big cities such as Helsinki or Tampere. The individuals commuting from nearby towns from the surrounding areas increase the effect. In smaller towns the traffic congestion on roads is much lower because the population is also smaller.

As the foregoing examples show there are many relevant differences between the travelling habits and characteristics in different sized towns and cities. These differences are important to take into account when the transport modes are compared with each other. When comparing modal energy consumption and greenhouse gas generation on two same length trips in different sized cities the specific influences of the surroundings have an effect on modal choice and other relevant issues connected to the trip.

2.1.2 Rural travel environment

The term rural environment is a relatively wide ranging expression. It is used in this study to describe both sparsely populated areas in the countryside as well as small municipalities with a small population. Finland is a relatively sparsely populated country with long distances between towns and cities. According to statistics Finland's population density is only 15 persons/km² (Statistics Finland 2012). Most of the people in Finland live in cities or towns and only about 20 % of the population lives in areas that can be classified as rural areas.

When searching the differences between rural and urban travel environments there are many characteristics that differ from each other. One of the most recognizable aspects is the fact that privately owned vehicles are on average in a much more important role in means of transportation in rural areas (Helminen 2009). The distances are also much longer and services more widely spread. In the sparsely populated areas with long distances between the small municipalities it is not unusual that there might be for example only one bus route operating in the area running only few times per day. For example in the *Kainuun runkoliikennesuunnitelma* 2009-2012 there are goals set for the Kainuu region's bus transport system. In the paper the presented target is that there would be at least one bus from each of the regions municipalities to the region center Kajaani in the morning throughout the year. Also there would be at least one bus heading from Kajaani to two of the nearby municipalities. In the afternoon there should be at least one returning bus line from Kajaani to each of the surrounding municipalities for commuters and school students to use. In addition there should be some bus lines during the day providing transport for shopping trips to the regions center Kajaani. As it can be noticed the bus line frequency makes the private car an only reasonable mode choice in some situations. It is also common that during weekends some of the routes are not operated at all (Turunen 2008). This makes the privately owned vehicle a highly probable alternative to be used. The owning and using a private vehicle in rural areas is also easier and cheaper than in urban areas when parking fees and finding parking spaces are not an issue. In summary the private car performance is high compared to other transport modes in the rural areas (Helminen 2009).

A specific characteristic in the rural environment is also that the daily trip lengths are in average often notably longer than in urban areas. This is because the different services are situated in the nearby towns or municipalities. One must travel longer distances to reach them whereas the number of trips travelled per day in the rural areas is lower than in the urban areas (Helminen 2009). This result of the fact that people often combine the different trips they need to travel to one longer trip because of the distances. For example it is not sensible to travel 50 kilometers to a grocery store and after a couple of hours drive another 40 kilometers to the same direction to visit a hardware store. A better alternative is to combine both to be done during the same trip in order to save time and expenses.

The traffic volumes on rural roads are quite low as a result from the low population density. Therefore the delays caused by traffic congestion are not an issue and the movement on roads is much more independent of for example the time of day. One exception to this are the annual holiday seasons and also increased traffic during weekends when people travel to the rural areas to their summer cottages or other activities. Especially during the summer season and other annual holidays Finnish people travel more in the country compared to other time of the year (Finnish Transport Agency 2012). On these periods some of the roads near to holiday resorts or nearby areas get a notable increase in their amount of traffic. Also the traffic intensity on the main rural area highways increases during these periods. However this situation occurs only a few times per year and lasts only for a short period of time and is not relevant when the average rural environment traffic characteristics are examined.

In the Figure 1 is demonstrated the change of population in different parts of Finland between the years 2000-2005. As seen in the picture the rural area population has increased only near some of the biggest cities and the Helsinki metropolitan area. Further off from the cities the population has decreased. Similar development still continues and as it continues further it will make people more dependent on private cars as the upkeep of a functional public transport will become difficult and unprofitable for the operator as the population decreases (Riikonen 2008).

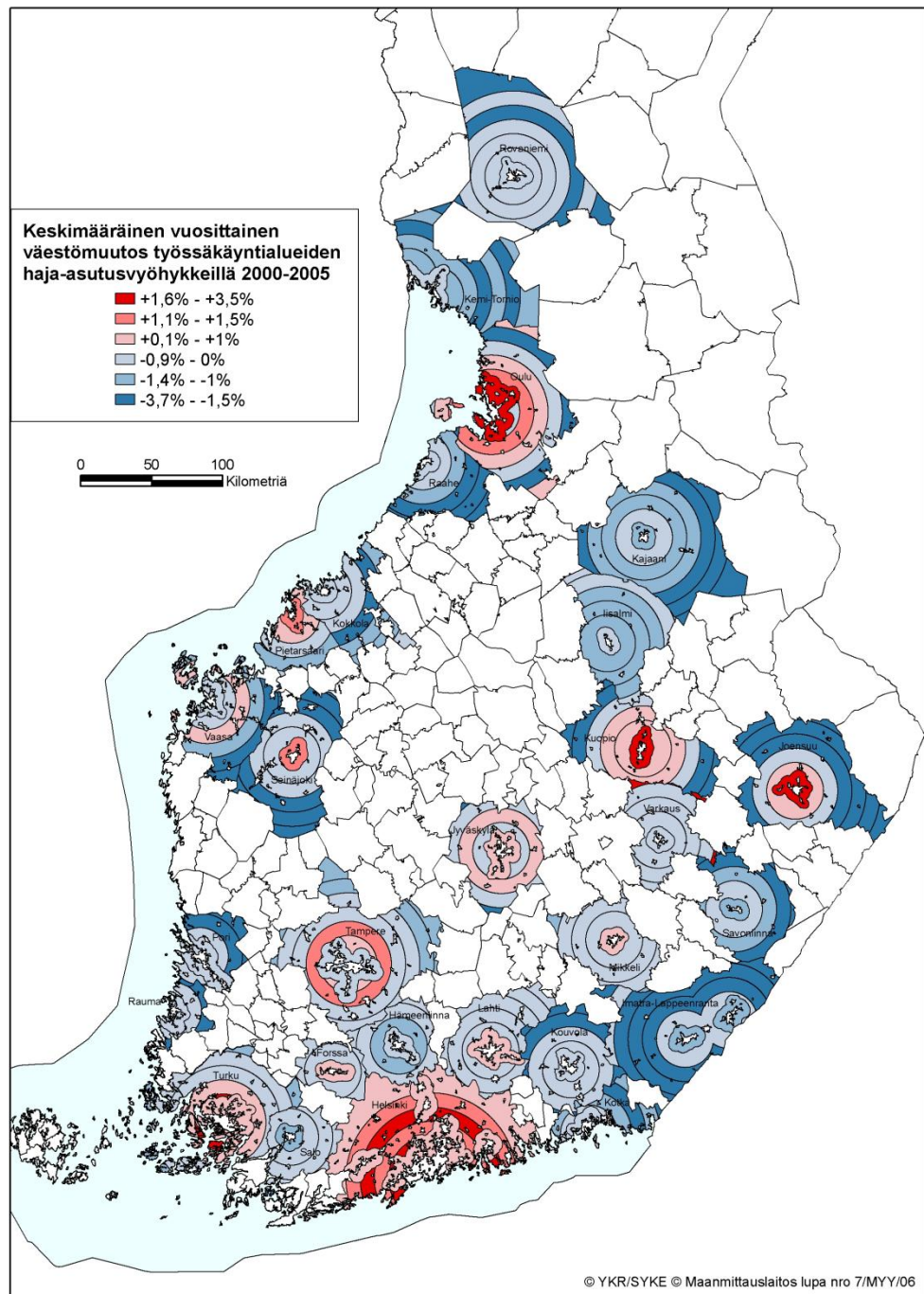


Figure 1. The change of Finnish rural area population (Helminen 2009).

Nowadays the structure of the society tends to scatter widely to the areas surrounding the biggest cities, whereas the population in other remote rural areas and near medium sized towns is decreasing (Finland's environmental administration 2012). Some of the reasons for this development are the fact that the supply of properties does not answer

the demand especially in some of the growing cities. Also the lower land and building costs in the rural areas compared to urban areas draw people further off from cities (Helminen 2009). Consequently the commuters must travel longer distances to work and this increase the greenhouse gas generation. Building up an effective and suitable public transportation network to the fast growing areas takes also time and therefore private vehicles play a key role in those areas (Riikonen 2008).

2.1.3 Long distance travel

Long distance travel environment differs from the previous travel environments demonstrated earlier in the chapter. The travel environments described above are strongly related to and influenced by the surrounding area whereas the long distance travel environment is not related to any specific spatial context. A long distance trip can begin from an urban area and end up to a remote rural area. The long distance travel environment is related to the trip length. The term long distance travel is used in this study to describe trips with a length over 100 kilometers. The trips that are included in this context are much longer than the average daily trips which length is on average 14,3 kilometers/trip in Finland (Finnish Transport Agency 2012). Long distance travelling is therefore examined as an own trip category in order to demonstrate the characteristics that are different compared to travelling short distances.

The term long distance travel is used in this study to describe long intercity trips that are travelled inside the Finnish borders. It is estimated that the total number of long distance trips (over 100 kilometers/trip) Finns travel annually is approximately 100 million trips. That is approximately 23 long distance trips travelled per person every year (Finnish Transport Agency 2012).

About 70 % of the total number of annual long distance trips travelled in Finland are recreational trips which include visiting relatives, other travelling and travelling to summer cottages. About 22% of annual long distance trips in Finland are related to working or education, including business trips, travelling long distances to school and other work related trips. The remaining 7% of annual long distance trips are trips related to shopping (Finnish Transport Agency 2012).

The Figure 2 shows an example of long distance travelling in Finland and demonstrates how the number of long distance passenger trips travelled by trains on railways is composed in different parts of the countries railway network in year 2011. The numbers and shades in the picture symbolize millions of trips travelled on each section of the Finnish railway network.

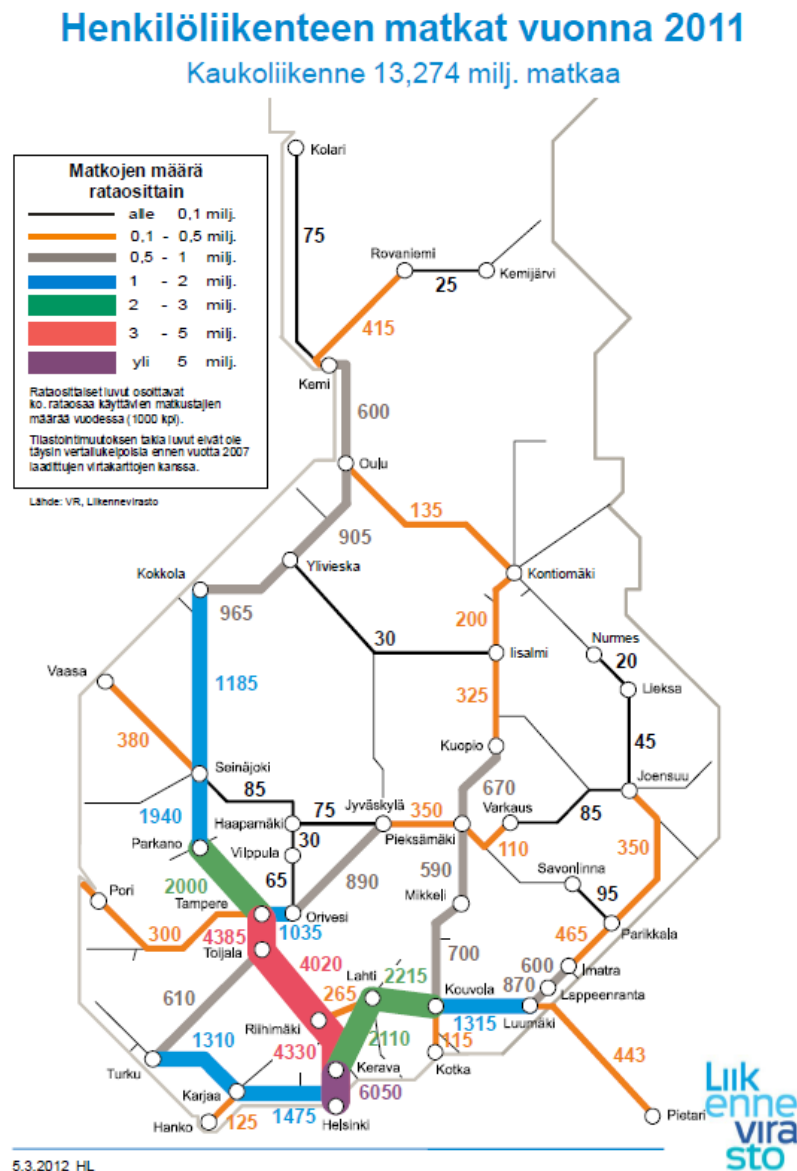


Figure 2. Trip distribution to the railway network in 2011 (Finnish Transport Agency 2012).

There are fewer reasonable transport mode alternatives to be used in the long distance travelling compared to for example the shorter trips travelled in urban environment. In Finland long distance trips are often travelled by private vehicles which are the most

common transport mode in this trip category. In addition to the private car the most common public transport modes used for longest trips inside Finland are usually trains and airplanes. Also intercity buses are used (Finnish Transport Agency 2012).

2.1.4 Very long distance trips abroad

In this study the term very long distance travelling is used to describe the trips that are travelled outside the Finnish borders to Europe and to other further continents. The total number of over 100 kilometer long trips that Finns travel abroad annually is 12 million and the amount of both recreational and business trips are increasing (Finnish Transport Agency 2012).

The most common reason for travelling abroad is tourism with the share of 59 % of all trips. Work related trips play also a significant role with the share of 18 % of all trips abroad (Finnish Transport Agency 2012).

In very long distance travelling the variety of different realistic transport modes to be used is much smaller compared to shorter trips. In the longest trips abroad the only realistic public transport mode to be used is airplanes. Private vehicles and buses are also used in some cases when the distance is shorter for example when travelling to European countries. Ships are not compared with other transport modes in this study. Especially in very long distance travelling it is common that besides the main transport mode there is one or more additional transport modes used during the trip. For example when travelling by airplane to a faraway destination some other transport mode such as bus or private car is used for the journey from home to the airport and from the airport to the final destination (Finnish Transport Agency 2012).

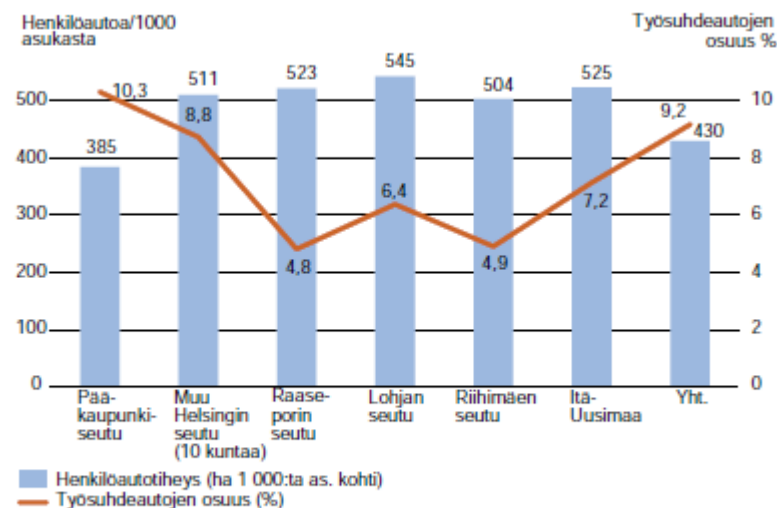
3 Transport modes and propulsion

3.1 Transport modes included for comparison

3.1.1 Private vehicles

In the developed and wealthy countries energy use and travel for personal transportation is dominated by automobiles (Schipper et. al. 2008). Finland is a very motorized country partly because of the long distances. In Finland there are approximately 518 vehicles/1000 persons. Private vehicles make up over 85 percent of the total road traffic vehicles registered in Finland (The Finnish Information Centre of Automobile Sector 2012). In Finland the most common transport mode used for travelling is the private car. Approximately 58 % of all trips Finnish people travel are travelled by private cars (Finnish Transport Agency 2012). The average distance a Finnish person travels by car per day is 29,9 kilometers. For public transportation the same number is only 8,0 kilometers per day (Finnish Transport Agency 2012). Private car is therefore a very important travel mode especially in the rural areas where the percentage of trips travelled by private cars is higher than in urban areas.

The number of private cars in the Helsinki metropolitan area and nearby areas is 630000 cars (approximately 430 cars/1000 persons). In addition there are major differences in the private car density in different areas (HSL 2010). In the Figure 3 below can be seen the differences of car ownership in different areas near the Helsinki Metropolitan Area. The numbers describe the number of private cars per 1000 persons and the share of company cars of the total amount of vehicles.



Henkilöautotiheys ja työsuhdeautojen osuus LITU-alueella vuonna 2008.

Figure 3. Amount of private cars in Finland in 2008 (HSL 2010).

The number of private cars owned in a household varies. 49,6 percent of Finnish people belong to a household which owns a car and 29,3 percent of people to a household which owns two cars. In contrast 16,7 percent of Finns do not own a car at all (Finnish Transport Agency 2012).

Gasoline and diesel engines are the most commonly used propulsion in private cars. The majority of engines in private vehicles are gasoline engines. In recent years the new car sales have divided almost equally between gasoline and diesel powered vehicles (The Finnish Information Centre of Automobile Sector 2012). When the whole private vehicle fleet is observed the share of gasoline vehicles was 79,1 percent in the year 2011. Share of diesel vehicles was respectively 20, 8 percent. The other propulsion alternatives are still a minority when the whole vehicle fleet is taken into account (The Finnish Information Centre of Automobile Sector 2012).

3.1.2 Pedestrian and bicycle

Walking and using bicycle is an important mode of transportation especially in short urban area trips. Especially in small towns where the level of public transport service is not as high as in larger cities the significance of walking and using bicycle is notable. Walking and using bicycle form a relatively notable share of the trips Finnish people

travel. About 32 percent of all domestic trips are travelled either by foot or using bicycle. Nine percent of these trips are travelled by bicycle (Pyöräilykuntien verkosto ry 2012). The number of trips travelled by foot or bicycle has been decreasing as people have begun to use faster motorized transport modes instead (Finnish Transport Agency 2012).

The condition, wideness and density of the existing walkways and sidewalks are also important for other transport modes. Improving the accessibility to public transport stations and stops also improves public transport. The reason is that where some public transport mode is the main mode used, almost always part of the trip is travelled by foot or by bicycle (Pyöräilykuntien verkosto ry 2012).

About one third of all trips are travelled by foot or bicycle but the trip lengths are short and therefore these trips form only a small part of the total kilometers an average individual travels per day. The average length of a trip when using bicycle as transport mode is 3 kilometers (Pyöräilykuntien verkosto ry 2012). An average person living in the Helsinki metropolitan area travels 25 kilometers per day. Only 2 kilometers are travelled by foot or bicycle (HSL 2010).

3.1.3 Motorcycle and moped

Motorcycles have become one of the fastest growing transport modes in Finland during recent years. During 1950-1960 a motorcycle was often the only means of transportation in a family and it was used throughout the year. When private cars became general the number of motorcycles decreased rapidly. In 1990 and after, motorcycles have again become very popular. In the year 2010 there was over 220000 motorcycles in use in Finland. The number of new motorcycle registrations has nevertheless decreased during last years (Liikenneturva 2012).

In Finland motorcycles are commonly used during a relatively short period because the winter months limit the use of motorcycles and mopeds. The number of motorcycles has increased steadily during recent years and also the number of accidents where motorcycles are involved in. Approximately 8 % of all traffic fatalities are motorcyclists (Liikenneturva 2012).

Mopeds are a popular means of transportation especially among young people over 15 years old. The popularity of mopeds has increased during recent years (City of Helsinki 2012). The increase is due to the new more comfortable and safer models which have also improved technically (Liikenneturva 2012). The technical improvement of engines has lowered the rate of emissions of mopeds especially when two stroke and four stroke engines are compared (VTT 2012).

According to research mopeds are the most dangerous means of transportation per kilometer distance compared to other vehicles. The risk for getting involved into a serious accident with a moped is over ten times as much as for normal private cars. Most of the moped drivers are young people with lacking knowledge of traffic regulations and who take unnecessary risks while driving (Liikenneturva 2012).

3.1.4 Urban and intercity buses

In Europe the urban and intercity buses are one the most popular transport modes in after automobiles (Turunen 2008). In European countries buses are generally considered as a safe and easily accessible transport mode in urban areas as well as in rural areas and long distance travelling (Turunen 2008). In Finland buses are one of the most common public transport modes in biggest cities and especially in small town environment. In the Helsinki metropolitan area buses are used to complete the public transport network where metro and regional railway networks form the framework of the system (HSL 2010). All of the feeder lines and cross traffic in the Helsinki metropolitan area are also operated by buses (HSL 2010). The heavy increase of passenger cars and the population's concentration to towns and cities has reduced the number of bus passengers on rural areas in the last decades. At the same time intercity express bus routes and urban bus routes in the Helsinki metropolitan area have gained more users (Turunen 2008).

There is a great variety of buses with different characteristics operating in different purposes. The bus sizes and interior design such as the arrangement of seats vary depending on their use (Vuchic 2007). Most buses have single body but some of the buses operating in the Helsinki metropolitan area and other large city bus routes are articulated in order to attain additional capacity (Vuchic 2007). Low-floor buses are commonly used in urban areas making the boarding and alighting easier. Contrary intercity buses

are normally high-floor buses (Vuchic 2007). The capacity of buses can vary widely between 14 passengers (minibus) and 140 passengers (double-articulated bus) (Vuchic 2007). Figure 4 demonstrates yet another bus size used relatively rarely in Europe, 14.5m low-floor bus used in the Jokeri-line in the Helsinki metropolitan area.



Figure 4. A 14.5 meter long low-floor bus used in the Jokeri-line (HSL 2010).

At the moment the majority of buses are using diesel powered engines in Finland (HSL 2010). Natural gas powered engines are also used in urban area public transport but there were only 100 gas engine buses operating in the Helsinki metropolitan area in 2011 (HSL 2010). The buses used to operate the intercity routes are powered only by diesel engines at the moment. In other countries there are also other propulsion systems in common use such as electric and hybrid buses. Diesel-electric hybrids are also being phased into the bus fleet (Vuchic 2007).

3.1.5 Metro

Metro networks are common in large cities all over the world. The networks vary by length and density depending on the population and size of the city where operating. The world's northernmost metro system was built in Helsinki in the year 1982 and it has been serving the city's public transport since (HKL 2012). Helsinki's metro network consists of 17 stations and its total length is approximately 21 kilometers (HKL 2012). The metro network connects the Helsinki downtown area and the eastern suburbs. The metro system is considered to be very reliable transportation mode and it transports an-

nually approximately 58 million passengers (HKL 2012). An extension westbound is currently under construction and it is supposed to be opened for operation in the end of 2015 (Länsimetro 2010). The extension will improve travelling between southern Espoo and Helsinki adding metro as an alternative transport mode in the area. In the Figure 5 below is shown the Helsinki area metro network as it appears at the moment.



Figure 5. Helsinki metro network (HKL 2012).

Choosing metro as a transport mode is possible only in Helsinki area. Nevertheless it is a notable and popular transport mode in the area and therefore also included in the dense urban area modal comparison. Special characteristics for the metro system are that the usage is restricted to only a limited area and that there is often another transport modes for example bus feeder lines used to get to the stations.

There are two types of trains operating in the Helsinki metro system. These types are older M100 and newer M200. Both of these train types are electric powered. In operation there are usually 4 or 6 carriages in one train. During weekdays in peak hours there are 15 trains which each consist of 6 carriages operating in the same time in the network (HKL 2012).

3.1.6 Regional rail in southern Finland

Metro and regional rail systems are common in large cities all over the world. Also in Finland the backbone of the public transport system in the Helsinki metropolitan area is formed by the metro and regional rail networks. The Helsinki downtown area is being built to rely on those rail transport modes and the bus network is used to complete the whole public transportation network in the area (HKL 2012).

The regional railway network is essential for commutation in the Helsinki metropolitan area and also from the surrounding region. It links the major centers and suburbs to the Helsinki city center and to each other. Additional rails have been built to moderate the most heavily congested parts of the network such as Helsinki-Leppävaara (completed in 2002) and Helsinki-Tikkurila (completed in 1996) (HSL 2010). In the year 2006 a direct railway line between Kerava and Lahti was completed. This improvement made the journey from Lahti to Helsinki area faster and drew more commuters to use trains for their way to work (HSL 2010).

The regional railway network joins the main centers of the Helsinki metropolitan area together and the network ranges up to Karjaa in the west and to Lahti and Riihimäki in the north. The network is shown in the Figure 6 below. Railways are shown in black color and the roads and highways in gray color with road numbers. The total length of the regional rail network is approximately 80 kilometers (Junakalusto 2012).



Figure 6. Helsinki area regional railway network (HSL 2010).

3.1.7 Intercity rail

The nationwide railway network creates a frame for the intercity public transport in many countries. This is also the situation in Finland. Finland's railway network connects the country's major cities and towns and it covers most of the country with the exception of the northern parts of Lapland. In the year 2012 the total length of the railway network in Finland was approximately 5944 kilometers. Slightly over a half of the railways, 3073 kilometers are electrified (Finnish Transport Agency 2012).

The intercity railway network as it is in the year 2010 is presented in the Figure 7 below. The electrified parts of the network are presented with red color and the gray colored parts present the parts of the network which are no longer operated. The railway network is much denser in the southern parts of the country and becomes looser when moving north.

The majority of trains used in rail passenger transport in Finland are powered by electricity (VTT 2012). Intercity 2 and Pendolino trains are used in the operation between the biggest cities. Pendolino trains operate between Helsinki and Oulu, Turku, Jyväskylä, Kuopio, Joensuu, Kouvola, Iisalmi and Kajaani. There are also different types of regional trains operating shorter routes, for example the Sm4 train (VR Group 2012).



Figure 7. Finland's railway network. (VR Group 2012)

3.1.8 Airlines

There are many different airplane types which are all used in different types of flights. The majority of commercial airlines fly their flights with turbofan airplanes. However turboprop engine planes are used in a notable number of shorter domestic flights. 59% of short domestic flights (length shorter than 250 nautical miles, 463 kilometers) are flown with turboprop aircraft. Turboprop aircraft is also used in some long domestic

flights (length over 463 kilometers) with low demand and in short flights to Europe (VTT 2012).

Both turbofan and turboprop engines consume kerosene as fuel. The exhaust fumes and greenhouse gases generated are much the same as in other road vehicles. The amount of carbon dioxide and water vapor is commensurate to the amount of fuel used. The amount of other generated components varies in different flying situations. They are affected by the engine type and takeoff weight of the aircraft (Ministry of Transport and Communications 2012).

The energy efficiency and greenhouse gas generation of different aircraft has decreased by almost half compared to the amounts in 1970's. Nowadays the long range jet engine aircraft consume approximately 3 liters of fuel/passenger/100 km. Shorter range jets consume approximately 3-5 liters of fuel/passenger/100 km and turboprop aircraft consume 3-4 liters of fuel/passenger/100 km. These numbers occur when the aircraft's capacity is fully used. In conclusion the long distance flights are more energy efficient and environmentally cleaner than shorter flights (Finavia 2012).

3.2 *Propulsion alternatives*

3.2.1 Gasoline vehicles

The gasoline engine is especially used in small and medium sized private vehicles and mopeds and motorcycles. It is much more uncommon in larger vehicles (Motiva 2012). Even after diesel vehicles have become more and more popular in Finland and especially in other European countries the gasoline engine is still the most popular engine type in Finnish private vehicles. In the year 2007 approximately 86 % of all vehicles were powered by gasoline (Motiva 2012). An average individual gasoline powered vehicle is still usually not driven as much as average diesel powered vehicles because diesel powered cars have commonly been larger and being used more often. There are still notable differences in the amount of kilometres driven even as the smaller diesel vehicles have become more common (VTT 2012).

The efficiency coefficient of a gasoline engine is lower than in any other combustion engine motor types used in road vehicles. For example in gasoline engines the energy coefficient is approximately 20-25 % when in a diesel engine it can be even 40 % (Motiva 2012). Modern gasoline engines generate less Nitrogen oxides and particulate matter than diesel engines. The catalytic converter which is implemented in every new gasoline vehicle since 1990 when they became obligatory in new cars has lowered the emissions notably compared to older vehicles without the catalytic converter (VTT 2012). On the other hand the carbon dioxide emissions of a gasoline engine are higher compared to diesel engines (Motiva 2012). Besides gasoline the normal gasoline engines can use fuel which contains gasoline and maximum of 5% ethanol to reduce the environment effects. From the beginning of year 2011 there has been available a gasoline mixture that contains maximum of 10% of ethanol. This fuel has become the most sold gasoline type in Finland as it can be used in over 70 % of the whole gasoline car fleet (Motiva 2012).

3.2.2 Diesel vehicles

Diesel powered engines have been the most common propulsion type for larger vehicles such as trucks, buses and tractors and light trucks for a long time. Their frequency among passenger cars and SUVs has also increased significantly in the past decade and continues growing in most countries (Schipper et. al. 2008). The foremost reason for this development is the growing awareness of the effects of greenhouse gas emissions and the worldwide trend on trying to reduce the production with diesel powered vehicles that are thought to be consuming less fuel than gasoline engines. When the diesel powered car fleet is examined world widely the share of diesel cars has grown steadily. By the year 2006 more than half of all cars sold in the European Union were diesel powered (Schipper et. al. 2008).

Traditionally diesel cars have been in a much greater role in the Southern European countries but even in the northern countries the share of new diesel cars has risen significantly (Schipper et. al. 2008). The situation is the same also in Finland as seen in the Figure 8 below. The share of diesels in the new registrations and in the total car fleet has risen steadily. Since the year 1990 the share of new diesel powered cars sold has grown until it reached the share of 50 % in the year 2008. Since then the share has de-

creased slightly. In the year 2011 the share of new diesel cars was only 42 %. Finland has relatively high taxation rates for diesel powered vehicles compared to gasoline powered ones. This affects and slows down the growth of the diesel powered vehicle fleet (The Finnish Information Centre of Automobile Sector 2012). The annual diesel tax which is not reliant on the yearly distance driven constricts households to purchase a diesel car for a second family car.

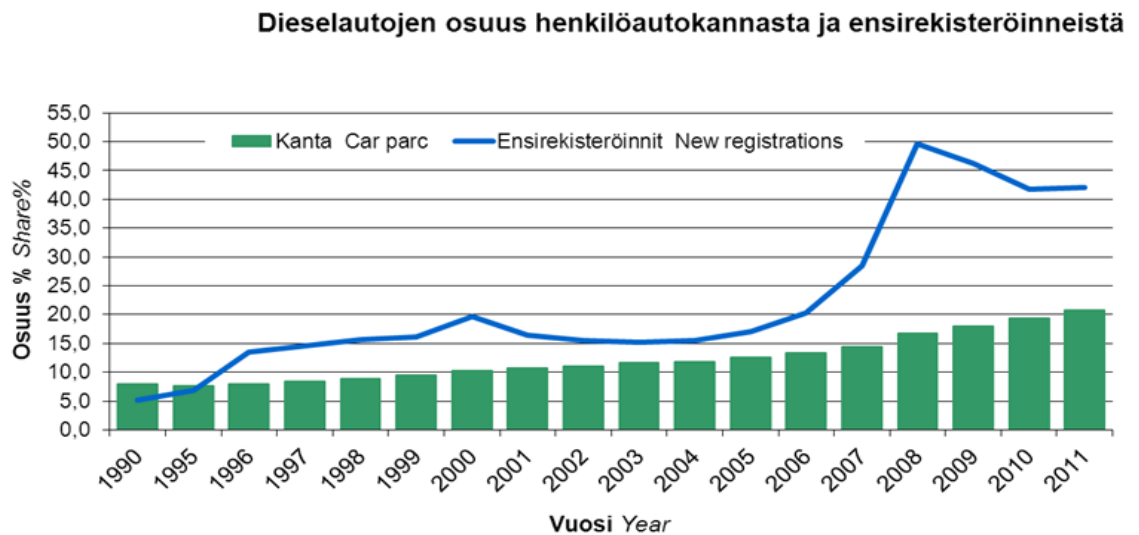


Figure 8. Share of diesel vehicles in Finland. (The Finnish Information Centre of Automobile Sector 2012)

The fuel economy of different vehicles differs a lot and it depends for example on the size of the vehicle and the engine and the driving technique how the car is driven. The fuel consumption in liters per 100 kilometers of a diesel car is on average lower than in gasoline cars when comparing a same sized vehicle (Schipper et. al. 2008). When observing the entire car fleet in Finland the average diesel vehicle fuel consumption in liters in l/100 kilometers is 6,5/100 km (VTT 2012). In newer cars the fuel efficiency is better.

There are notable differences in the average annual distances driven by diesel cars compared to gasoline cars. The number varies by countries but studies indicate that diesel cars in Europe are driven over 40 to 100 percent more per year than gasoline cars (Schipper et. al. 2008). Diesel cars are often used as first family cars and therefore they

are used more and driven longer distances. Using diesel powered cars for businesses for example taxis increases the average annual amount driven.

3.2.3 Hybrid vehicles

Hybrid vehicles are one of the outputs which the development work and research for alternative energy sources has brought about. Hybrid technology generally combines internal combustion engine and electric motor to optimize energy use for propulsion (Vanek et. al. 2008). Combining the two engine types in same vehicle enables the usage of the best features of both engines. The energy efficiency improves especially in city traffic (Kallberg 2009).

The term hybrid vehicle can refer to a variety of automobiles with different technologies implemented. The term hybrid vehicle can refer to two different types of propulsion. These types are HEV (hybrid electric-vehicle) and PHEV (plug in hybrid electric vehicle) (Vyas et. al. 2009). The HEV vehicle gets most of its propulsion from a common internal combustion engine and the electric motor gives additional power when needed (Kallberg 2009). HEV vehicles capture the advantages of both engine types and avoid some of the disadvantages of each (Vanek et. al. 2008). The HEV vehicles can be divided into several categories depending on differences in the vehicles power transmission or the power source ratio (full or half hybrid) (Vyas et. al. 2009). In addition the HEV hybrids are fully dependent on the internal combustion engine which recharges the vehicles batteries while moving or salvaging the energy developed while slowing down the vehicle. Additional charging is not needed in these vehicles (Kallberg 2009).

As opposed to HEV the PHEV vehicle gets the greatest proportion of its power from the electric engine. PHEV vehicles are on development stage and some car manufacturers have brought PHEV models on market (Biomeri 2009). These vehicles need an external power source to charge the batteries. The technique in these vehicles is close to electric cars. The sizes of the batteries are smaller (Kallberg 2009). Figure 9 shows Toyota's most popular HEV model the Toyota Prius.



Figure 9. Toyota Prius hybrid (Toyota 2012).

Currently hybrid vehicles make up only a small part of the world's private car sales but rising fuel costs and concern about the environment have increased their share continuously (Vanek et. al. 2008). In recent years the number of hybrid vehicles in Finland has increased tenfold. In year 2006 there was only 224 hybrid vehicles registered in Finland and in august 2010 there was already 2556 vehicles registered (Biomeri 2009).

3.2.4 Alternative energy sources

Biofuels and other alternative energy sources are in center stage when the energy consumption and greenhouse gas generation of road traffic is reduced. The usage and implementation of different biofuels and other alternative energy sources will assist on reducing greenhouse gas generation, improve road traffic energy efficiency, increase the self-sufficiency of energy sources and contribute the competitiveness of cleaner energy sources (Kallberg 2009).

There are alternative fuels that are in use or can be used as replacement for traditional gasoline and diesel powered engines in the future. Fuel mixtures of gasoline and ethanol which the majority of vehicles are able to use are on the market. There is also flexi-fuel and natural gas powered vehicles on the market although their market share is still marginal. Flexi-fuel vehicles can use fuel mixtures consisting up to 85 percent of ethanol (Kallberg 2009). These vehicles using natural gas or ethanol are usually also able to use gasoline when the other fuels are not available (Trafi 2012). There are approximately 800 gas powered vehicles in use in Finland. They are commonly private vehicles or buses, taxis, garbage trucks or delivery vehicles. In Europe there are already 1,3 million gas vehicles on the roads and the amount is rising (Motiva 2012).

4 Trip classification and categorization

4.1 *Different perspectives*

4.1.1 Trip purpose

There is not one definite way to categorize and classify trips and there are several different perspectives on how to approach the issue. In this chapter some of those different approaches are introduced and in the following chapter 4.2 example trips are formed for modal comparison. The example trips are formed and categorized based on the different perspectives demonstrated below.

Trip purposes: Commuting, School, Shopping, Social, Leisure

Time of travelling: peak hour versus off peak, weekday versus weekend, holidays

Number of modes used: only one mode versus multimodal

Origin and destinations: simple round trip versus trip chain

The first way to categorize trips is based on trip purpose. Some people travel to work every day at the same time of day using the same transport mode. Some people spend their free time driving for fun on weekends. Some take a bus to the grocery store every afternoon. These are examples of trips that differ by the purpose and time of day they are travelled. It has been surveyed that about 28 % of daily trips that Finnish people travel are somehow related to work, school or education. 35 % of trips are related to shopping or conducting. The remaining 37 % of the trips are leisure trips with different purposes (Finnish Transport Agency 2012).

The categorization of trips by their purpose can be done in many ways. In Alan Hobacks article Transit as Part of the Equation, Revisited the energy consumed per passenger in the Toronto's (Canada) transit system was investigated. In the paper the transit trips were divided into 6 groups by trip purpose as the following Table 1 shows.

Table 1. Trip categorization by purpose. (Hoback 2009, p. 56)

Purpose of transit trips
Work
School
Shopping
Medical
Social
Other

The foregoing categorization was done just for transit trips travelled in a specific city transit system. When the trips are analyzed in a larger scale taking into account different transport modes and longer distance trips the trip groups turn different. According to The National Passenger Transport Survey a Finnish person travels on average 2,9 trips per day. In the survey the trips which include all domestic trips in Finland are divided into 7 groups by trip purpose. These groups are demonstrated in the Table 2 below.

Table 2. Finland's domestic trips grouped by trip purpose (Finnish Transport Agency 2012, p. 26)

Purpose of trip	Share of average trips/day
Commuting	17%
School, education	7%
Trips during work, other work related trips	4%
Shopping	35%
Visit	11%
Cottage	1%
Other leisure trips	25%

The purpose of the trip also affects other characteristics of the trip. Different trips with different purposes are travelled with different transport modes. In some cases some of the transport modes can be discarded as possibilities right away. In Finnish domestic trips public transportation is used especially when commuting or travelling trips related to school, education or shopping. When travelling longer distances to summer cottages or visiting relatives the private car is most commonly used and public transportation

modes are more uncommon (Finnish Transport Agency 2012). One reason for this is that the amount of possessions arrived along on this type of trips limit the usage of public transportation and often requires the use of private cars. The same situations prevail for example during trips to hobbies when the equipment is heavy and require storage during travelling.

4.1.2 Time of travelling

The temporal variation of different trips is often related with the purpose of travelling. Also the transport mode used or the possibility of using specific transport mode has effects and sets limitations on the time of day the trip is possible to travel. For example in the Helsinki metropolitan area and surroundings 12% of all daily trips travelled using public transportation are travelled during the morning peak hour (7am to 8am) (HSL 2010).

When trips are categorized by the purpose of the trip it is also necessary to take the temporal variation and its effects into account. The time of day when a certain trip is travelled has effects on different issues. The duration of the trip is partly related to the amount of traffic on the road which depends on whether it is morning or afternoon, day or night. Variables which are relevant when calculating modal energy efficiency per passenger are modal load factors. They are affected by the period of day the trip is travelled. Load factors of different public transport modes vary a lot between the morning and afternoon hours compared to evening and night time. Also the differences between weekdays and weekends have effects on the amount of persons travelling.

Travelling characteristics and behavior during weekdays (Monday to Friday) is quite similar. Commuting, education and school related trips and other work related trips are commonly travelled during weekdays. The majority of all types of holiday and other leisure trips are commonly travelled on weekends (Finnish Transport Agency 2012).

The temporal variation of commuting is different compared to trips with other purposes. The majority of commuters travel on weekdays during peak hours in the morning and afternoon. School and education related trips divide respectively about the same way (HSL 2010). Trips with other purposes divide more evenly throughout the day.

4.1.3 One mode or multiple modes

Another aspect of categorizing trips is categorizing them based on the amount of different transport modes used to travel a certain trip. Trips can be divided into ones which are travelled using only one transport mode during the entire trip or to ones which are travelled using two or more different transport modes. When a trip is travelled by using two or more means of transportation the total energy generated is much more complex to investigate when compared to a case where only one mode is used during the entire trip.

83 % of all trips travelled in Finland are ones which are travelled using only one transport mode for the whole trip. The rest of the trips are travelled using two or more modes. It is typical that for trips where the main transport mode is public transportation another mode is often required for the rest of the trip. For example, when using bus, train or airplane another mode, for example private car is commonly used to travel from the a start point of the trip to the station or airport. Also after the part of the trip travelled by public transportation another mode is needed to travel the final part of the trip to the destination. In dense urban environment walking is a very important travelling mode. It is used especially on short trips and during most public transport trips when accessing the public transport terminals and stations (Finnish Transport Agency 2012).

For trips where the main transport mode is private car it is possible that after a certain part of the trip the vehicle is parked to a feeder connection parking area. The rest of the trip is travelled using another transport mode which is usually some sort of public transportation. The majority of people using the parking areas are commuters. It has been surveyed that 88 % of the total private car users that parked their vehicle in the feeder connection parking areas were on their way to work (HSL 2010).

Feeder traffic is the part of the trip from the origin to the terminal where the main transport mode begins its journey. In the intercity trips where the main transport mode is either intercity bus or intercity train the most common feeder transport mode after walking is private car as a passenger or driver. Also other public transport feeder lines are common in long distance trips, especially urban buses. Urban bus feeder lines are the most common feeder transport mode after walking in both long distance trips and short

distance urban public transport trips. Especially in situations when the trips main transport mode is either metro or regional rail, the significance of urban buses as feeders, grow higher (Finnish Transport Agency 2012).

The majority of people's daily trips are travelled between their home and for example to work, shopping or school. 79 % of all trips are home based meaning that the trips begin from home or end up to home (Finnish Transport Agency 2012). The term trip chaining is used to describe situations where an individual traveller links trips with different purposes into one trip in order to save time and add efficiency (McGuckin et. al. 1999). It is common that on the way to work or from work people also visit other destinations and create trip chains. The Figure 10 below demonstrates two trip chains, one from home to work and one from work to home.

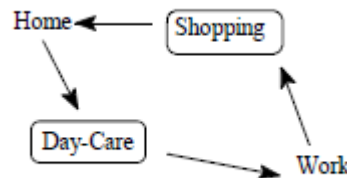


Figure 10. Example trip chain. (McGuckin et. al. 1999)

Trip chaining behavior and different daily travel patterns are individual and depend on many variables including the number and age of children in the household, working people against non-workers and the main trip purpose. It is also noticed that it is more likely to a person to make one or more stops when travelling from work to home compared to when travelling from home to work (McGuckin et.al. 1999).

4.1.4 Occupancy level and load factors

When comparing the energy efficiency of different transport modes the differences between generated emissions per kilometer differ a lot between them. Modal load factors are important to take into account when the focus is on how much the investigated transport mode generates emissions per passenger kilometer.

The term load factor actually has several different definitions, depending upon industry practice and data availability. First the capacity utilization coefficient is the ratio of ac-

tual passenger volume to the provided capacity, measured in space-kilometers. It is also commonly known as the space averaged load factor. The coefficient is used in scheduling public transport services, airline and railway services and in evaluating efficiency (Vuchic 2007).

Second, the load factor can also represent the simple ratio of the number of passengers in a vehicle to its total capacity, measured in spaces, or it can be the ratio of total passengers carried to total capacity offered by all vehicles on the same path, in both cases passing a fixed point or a line during a certain period of time (usually one hour). But since there is a large variation in spaces available in private vehicles, it is typical that statistics are expressed simply on a per vehicle basis rather than by size categories. The same often applies to buses due to the private nature of many bus fleets and lack of published data that is broken down by bus size (Vuchic 2007).

Load factors depend on different issues. The surrounding environment and population density affects the number of people travelling by public transportation. The difference between peak hours and off-peak hours is notable. For example in dense urban areas some of the bus lines are very crowded especially during rush hours whereas some bus lines in rural areas are usually running with only few persons aboard. The number of passengers also varies along the transport modes route and it changes during the day. The purpose of the trips and the time of day when the trips is travelled are also affecting the load factors as described in chapter 4.1.2. During morning and afternoon rush hours the buses and trains are usually full because of commuting and during night time there might be only few people in the vehicle depending on the route and surroundings.

Automobiles have lower occupancy levels than average for work trips (Hoback 2009). The average amount of people travelling in private cars in Finland is approximately 1,7 persons per vehicle. This number is an average of all types of trips and includes all trips travelled in Finland (Finnish Transport Agency 2012). As shown in the Figure 11 below the average load in a private car depends strongly on the purpose of the trip. During work trips there are only 1,1 persons on board compared to leisure trips where the load is on average 2,2 persons per vehicle (Finnish Transport Agency 2012). It is also common that there are more people travelling together as a group on longer trips compared to shorter ones. The occupancy level can also change during a trip when a person is

dropped off in a destination and the driver continues the travelling alone or returns back to the origin (Hoback 2009).

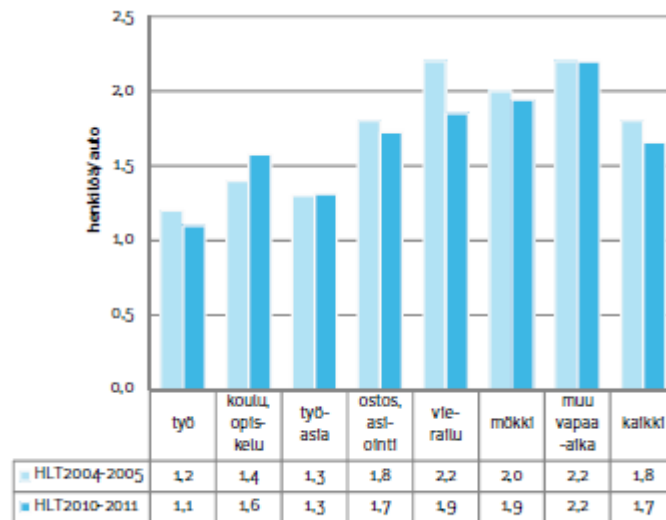


Figure 11. Average number of persons/auto relative to trip purpose. (Finnish Transport Agency 2012)

4.1.5 Mode choice scenarios

In different travel situations and in different spatial contexts the possibilities of choosing specific transport modes for travelling and the criterion used in choosing differs a lot. In some situations some modes can be discarded as realistic possibilities right away. In some situations there is only one transport mode available. In this chapter the selection scenarios of transport modes is introduced and different mode choice perspectives described.

According to (Vuchic, 2007) the balance between choosing private car or public transport in urban and dense urban areas depends on the following characteristics:

- The size and character of the city: physical form, population density and population characteristics
- Level of existing public transport network: available public transport modes (buses, metro, regional rail etc.) and the level and quality of service
- Auto travel limitations in the city: available parking facilities, streets for public transport only, city center pedestrian zones, limited access etc.
- Urban development policies and planning: land use planning, public transport systems planning and improvement

Private car ownership and the number of people owning a driving license plays a key role when the transport mode is chosen giving the possibility to travel also by car. When comparing the changes of the number of people owning driving licenses the amount has increased in the past 20 years in the Helsinki metropolitan area. When compared to the numbers in 1988 the size of the private car fleet has grown one and a half times bigger when the population has grown 26 %. Four persons out of five own a driver's license when the number was only 68 % 20 years ago. At the same time the number of women owning a driving license has increased and as the population grows older the driving license is common among the elderly. Women also use private car as a transport mode more often (HSL 2010).

There are differences of the level of public transport services and modes between different neighborhoods in the same urban area. Also the travelling habits in certain types of areas affect mode choice. In a dense suburb with the majority of people living in apartment buildings the local services such as small convenience stores, schools and other services are relatively near and often reached easily by walking or bicycle. In such areas where the regional structure is dense the public transport services are often easier to reach such as near the regional rail or metro network. In such areas choosing public transport is common. According to The National Passenger Transport Survey a person living in an apartment building suburb travel by public transport twice the amount than a person living in a more sparsely built one-family house suburb. The level of public transport services in one-family house suburbs is often not as effective compared to the

denser apartment suburbs. The available parking spaces for private vehicles differ in dense apartment suburbs compared to suburbs consisting of mostly one-family houses. There are on average more available spaces for vehicles for persons living in one-family houses than those living in apartments or row houses (Kurri et. al. 2002). The available parking spaces between different areas have effect on the easiness and cost of owning a private vehicle or even two or more vehicles in a household. This occurs especially in dense urban areas where the amount of parking spaces is limited.

The amount of daily trips travelled by either private car or public transport has both increased during the past 20 years in the Helsinki metropolitan area. The share of public transport trips of all trips has simultaneously decreased from 46 percent to 42 percent. The result to this behavior is that the land use and travelling have both increased in the outskirts of the area. Services are often located more separated along the ring roads and private vehicles are therefore easy to choose. The separation of services drives individuals to use private vehicles if there is a vehicle available (HSL 2010).

The length and purpose of the trip has an effect on the transport mode choice. The shortest urban shopping and free time trips are often travelled by foot when the destination is relatively near and other transport modes such as private cars or public transport is not a reasonable choice. Also the short everyday work and school trips are often travelled by foot. Bicycle is used evenly in all relatively short trip situations except work trips and longer leisure trips (Finnish Transport Agency 2012).

The expenses and the ease of using and owning a private car have major influences on transport mode choice especially in urban areas. The distance from the parking area to the destination is an important criterion when individuals choose where to park their vehicles. It has also effects on the final mode choice. If there are no proper parking spaces available or the individual is aware of the fact that the parking areas are most likely full, choosing public transportation is more propable. It also seems that the increase of parking fares and other restrictions of private car usage in urban areas have more effect on mode choice than for example reducing public transport fares or improving their level of service (Kurri et. al. 2002). Proper parking areas near public transportation terminals and feeder connection parking areas makes using public transportation easier and increase the usage of public transport even in for some parts of the trip.

In rural areas the longer distances to everyday services usually require travelling by some kind of vehicle, either own car or public transport. The limited public transport services in most rural areas make people depend almost fully on private vehicles. Even if the public transport service operates on the main highway the accessibility from a remote rural home to the nearest bus stop is often poor due to the long walking distance (Pucher et. al. 2005). The distance from the trip origin to the nearest public transport station has a notable effect on individual's mode choice in both urban and rural environment. When the distance to the nearest public transport stop or station increases, the share of trips travelled by private vehicles also increases (Finnish Transport Agency 2012).

In addition to other attributes the habits of an individual person have notable effects on mode choice. When a person has gotten used to owning and driving an own private vehicle he/she is most likely to use it even if the journey costs more than using public transportation. According to (Karetie 2009) a notable number of respondents were ready to pay much more for the costs such as annual car tax for owning and a private vehicle rather than change to using public transport. On the other hand, the change in fuel prices had more effect on the private car usage. Many of the answerers had already limited or are ready to limit their private car usage if the fuel prices grow higher. Some of the answerers had limited their driving due to increasing awareness of the environment and had started using partly or fully public transport.

4.2 *Earlier research*

There has been various research of the greenhouse gas generation and energy efficiency of different transport modes done in the past. Also data of travel behavior and mobility of individuals is collected via different travel surveys, either nationwide or concerning just an individual city or area. In this chapter some of these researches and available data sources are introduced.

Technical Research Centre of Finland VTT has completed Calculation system LIPASTO 2009 which is a calculation system for traffic emissions and energy consumption in Finland. This calculation system covers all transport modes in Finland. The first version concerning only road traffic emissions was published in 1988. A calcula-

tion system LIPASTO which concerned all traffic modes was made in 1997 and comprised models for road traffic, railway traffic, waterway traffic and air traffic. All of the models are updated annually and the latest version is LIPASTO 2009. The figures and results from the LIPASTO calculation system are used as the official emission figures of Finland (VTT 2012).

Besides the area wide emission data also the data for a single driving occasion with different transport modes and for example calculating emissions for production plant transportation is needed. Source data, the mileage (tonne-kilometre or person-kilometre) and emission factor for the mileage (g/tkm or g/personkm) were not previously available in Finland. The figures from foreign countries or own calculations prevented proper comparison and therefore in the year 2000 the first 4000 figure unit emission data bank for all traffic modes was published (VTT 2012).

The national passenger transport survey which is performed every six years, gives nationwide information of Finnish mobility in different parts of the country. The data was collected in 1974 for the first time and the data for the most recent survey was collected in 2010-2011. A comprehensive high quality dataset of the travel habits and demographic, spatial and temporal variations in passenger trips is produced. The national travel survey includes daily trips as well as longer over 100 kilometer trips which are studied separately. The most recent survey (2010-2011) had a total response rate of 56 % and the quality of the study was monitored daily in the interview center and with separate quality tracking reports (Finnish Transport Agency 2012).

In addition to the national travel survey also smaller scale surveys are produced in Finland. The LITU 2008 is a traffic survey concerning the area of Helsinki metropolitan area and surrounding region from where people commute to the Helsinki metropolitan area. The survey was produced in 2007-2008 and it was the first done since 1987-1988. The survey covered 37 municipalities in the area surrounding Helsinki. The traffic environment has experienced major changes between the surveys and therefore it was important to update the data for public transport and land use planning and modeling (HSL 2010).

The survey presented information of the travelling habits in the region. A model of the areas traffic systems functionality was produced based on the information of the survey. The LITU 2008 consists of four part surveys which were interview survey, private vehicle destination survey, public transport destination survey and feeder connection parking survey (HSL 2010).

In addition the biggest cities in Finland gather information of their urban public transport passenger volumes. These data contains often passenger volumes travelling with different public transport modes and also temporal variation of the passenger volumes. Also data from rural area bus passenger volumes is gathered by the bus companies operating the lines but because the urban area bus services are produced by many individual bus companies, accurate passenger data is not publicly available.

The objective of this thesis is to gather information from the described existing data sources. The data of travelling habits and passenger volumes of different transport modes and the greenhouse gas generation of different transport modes is used to calculate relative greenhouse gas generation and energy consumption in different situations. The objective is to produce reliable information of the greenhouse gas generation and energy consumption amounts in different situations and take into account the modal load factors and travel practices of individuals.

4.3 Forming example trips for mode comparison

The example trips used in the modal energy efficiency comparison in this thesis are introduced in this chapter. As demonstrated in chapter 4.1 the trips can be categorized into groups in several ways depending on the different perspectives and approach. In order to compare transport modes greenhouse gas generation and energy efficiency in certain trip situations, example trips are used. The example trips used for modal comparison are formed by combining and applying the trip categorization methods demonstrated in chapter 4.1.

The trip categories which are listed below are based on different spatial contexts. Each category includes example trips with lengths and transport modes that are realistic in each specific spatial context. The National Passenger Transport Survey and Helsinki Metropolitan Region Commuter Survey were used as groundings when the example

trips were formed and suitable transport modes chosen for comparison. All of the different transport modes included for comparison in this greenhouse gas generation and energy consumption analysis are listed in the Table 3 below.

Table 3. Transport modes included for comparison.

Private vehicles	Buses	Rail	Airliners
Automobile	Intercity	Intercity Higher speed tilt train	Turboprop
Moped	Urban	Regional	Medium distance turbofan
Motorcycle		Metro	Long distance turbo- fan

4.3.1 Very long distance trips

In very long distance travel there is usually only one realistic mode of transportation to be selected: the airplane especially when travelling overseas to other continents. In trip examples to Europe private vehicles including automobile and motorcycle are included to the comparison. The very long distance example trip situations are included to the analysis first to examine how the energy consumption differs in the different cases and secondly in order to give information on how does travelling very long distance trips affect individual's yearly total energy consumption and greenhouse gas generation.

In the very long distance category there are 10 trip examples included which are listed in the Table 4 below. There are 5 intercontinental trips and 5 trips to Europe. In the intercontinental trips the only realistic mode choice is the airplane and therefore only airplane is included to the analysis. In the European trips besides airplane the other modes calculated are private vehicles including private car and motorcycle. For each trip the greenhouse gas generation and energy consumption are calculated for each transport mode separately. Information of the distances between the different destinations is gathered from Matkailijan info 2012.

Table 4. Very long distance example trips.

	Destination	Distance, km	Compared modes
	Intercontinental destinations		
Trip 1	Helsinki-Bangkok	7900	Airplane
Trip 2	Helsinki-New York	6640	Airplane
Trip 3	Helsinki-Dubai	4500	Airplane
Trip 4	Helsinki-Nairobi	6900	Airplane
Trip 5	Helsinki- Buenos Aires	12900	Airplane
	Destinations in Europe		
Trip 6	Helsinki-Oslo	790	Airplane, private vehicles
Trip 7	Helsinki-Berlin	1110	Airplane, private vehicles
Trip 8	Helsinki-Madrid	2950	Airplane, private vehicles
Trip 9	Helsinki-London	1820	Airplane, private vehicles
Trip 10	Helsinki-Athens	2470	Airplane, private vehicles

4.3.2 Long distance trips

The long distance trips include long distance trips inside Finnish borders. For comparison the trips are categorized into work related trips and leisure trips and trip purpose based equivalent load factors obtained from The National Passenger Transport Survey are used in private vehicles in each situation. There are 5 different length example trips from both categories included for the comparison. The work trip destinations are example cities in different locations in Finland. The leisure trip destinations are chosen based on the most popular holiday and summer cottage locations in Finland obtained from Statistics Finland. The transport modes included for comparison in long distance trips are private vehicles including private car and motorcycle, intercity bus and intercity rail. Also turboprop and medium distance airplanes are included because they are realistic alternatives in some domestic trip situations. The long distance example trips are listed in the Tables 5 and 6 below. For each trip the greenhouse gas generation per person and the energy consumption per person are calculated for each transport mode and realistic intercity travelling load factors are used for each public transport mode.

Table 5. Long distance example work trips.

	Destination	Distance	Compared modes
Trip 1	Helsinki-Tampere	180 km	Private vehicles, bus, train, airplane
Trip 2	Helsinki-Turku	170 km	Private vehicles, bus, train, airplane
Trip 3	Helsinki-Jyväskylä	270 km	Private vehicles, bus, train, airplane
Trip 4	Helsinki-Rovaniemi	825 km	Private vehicles, bus, train, airplane
Trip 5	Helsinki-Oulu	610 km	Private vehicles, bus, train, airplane

Table 6. Long distance example leisure trips.

	Destination	Distance	Compared modes
Trip 1	Helsinki-Levi	990 km	Private vehicles, bus, train, airplane
Trip 2	Helsinki-Kuusamo	800 km	Private vehicles, bus, train, airplane
Trip 3	Helsinki-Kajaani	550 km	Private vehicles, bus, train, airplane
Trip 4	Helsinki-Savonlinna	330 km	Private vehicles, bus, train, airplane
Trip 5	Helsinki-Oulu	610 km	Private vehicles, bus, train, airplane

4.3.3 Rural trips

The rural area trips are categorized into three categories including work, school and shopping trips. In each situation the trip purpose based equivalent private vehicle load factors obtained from The National Passenger Transport Survey are used. The transport modes included for comparison are private vehicles including private cars, motorcycle and moped and intercity bus. The example trips with lengths ranging from 10 kilometers up to 100 kilometers in each category show the amount of emissions and energy consumption for different vehicles in different length trips. The moped is included in the shorter (10-50 km) trips only. For each trip the greenhouse gas generation per person and energy consumption per person is calculated for each transport mode using realistic rural travelling load factors. The Table 7 shows the rural trips included for the analysis.

Table 7. Rural area work, school and shopping trips.

	Distance	Compared modes
Trip 1	10 km	Private vehicles, intercity bus
Trip 2	20 km	Private vehicles, intercity bus
Trip 3	50 km	Private vehicles, intercity bus
Trip 4	80 km	Private vehicles, intercity bus
Trip 5	100 km	Private vehicles, intercity bus

4.3.4 Small town trips

In small town travel environment the trips are categorized into three categories including work, shopping and leisure trips. In each situation the equivalent load factors based on trip purpose obtained from The National Passenger Transport Survey are used for private vehicles. The transport modes included for comparison are private vehicles and buses. There are different length trips in each of the three categories with lengths ranging from 1 kilometer up to 15 kilometers. For each trip the greenhouse gas generation and energy consumption are calculated for each transport mode using realistic load factors for small town environment. The Table 8 below shows the small town trips included for the analysis.

Table 8. Small town work, school and shopping trips.

	Distance	Compared modes
Trip 1	1 km	Private vehicles, bus
Trip 2	2 km	Private vehicles, bus
Trip 3	5 km	Private vehicles, bus
Trip 4	10 km	Private vehicles, bus
Trip 5	15 km	Private vehicles, bus

4.3.5 Dense urban trips

The dense urban trips are categorized into four categories including work, school, shopping and leisure trips. In each of the four categories equivalent trip purpose based load factors obtained from The National Passenger Transport Survey are used in private vehicles. The transport modes included for comparison are private vehicles, urban bus, regional rail and metro. There are different length trips in each of the four categories with lengths ranging from 1 kilometer up to 20 kilometers. For each trip the greenhouse gas generation and energy consumption are calculated for each transport mode using realistic load factors for dense urban travelling environment. The Table 9 below shows the dense urban area trips included for the analysis.

Table 9. Dense urban area work, school, leisure and shopping trips.

	Distance	Compared modes
Trip 1	1 km	Private vehicles, urban bus, regional rail, metro
Trip 2	5 km	Private vehicles, urban bus, regional rail, metro
Trip 3	10 km	Private vehicles, urban bus, regional rail, metro
Trip 4	15 km	Private vehicles, urban bus, regional rail, metro
Trip 5	20 km	Private vehicles, urban bus, regional rail, metro

4.3.6 Commuting between towns and cities

Commuting to another town or city is examined and transport modes are compared as an own category. The example trips in this category range from 20 kilometers to 100 kilometers. The transport modes included for comparison are private vehicles, intercity bus and regional rail. There are 5 example trips with different lengths. The load factor used in private vehicles is 1 and 2 persons per vehicle and full vehicles. The Table 10 shows the commuter trips included for the analysis.

Table 10. Intercity commuter trips.

	Distance	Compared modes
Trip 1	20 km	Private vehicles, intercity bus, regional rail
Trip 2	40 km	Private vehicles, intercity bus, regional rail
Trip 3	60 km	Private vehicles, intercity bus, regional rail
Trip 4	80 km	Private vehicles, intercity bus, regional rail
Trip 5	100 km	Private vehicles, intercity bus, regional rail

4.3.7 Case study

A final part of the transport mode comparison is a case study of 6 imaginary but highly realistic persons which all have different daily travelling habits. The comparison between these imaginary individuals gives information on how do the individual daily travelling habits and living environments affect the daily and yearly amount of generated greenhouse gas emissions and energy consumption. The 6 example persons and their travelling habits are generated based on the different spatial contexts and trip examples described above. The example persons are introduced in the following list.

2 persons from a rural area:

Person 1: Lives in a rural area. Person travels once per week 50 km for shopping by car. He works at home so he does not have to commute to work.

Person 2: Lives in rural area. He does not own a private vehicle and therefore uses public transportation and travels approximately 30 kilometers per day by bus on 250 work-days per year.

2 persons from an urban area:

Person 3: Lives in urban area and commutes 5 km per day on 250 workdays per year. He uses auto for commuting and also travels 4 trips per year to a summer cottage (200 km/trip).

Person 4: Lives in urban area and commutes 5 km per day on 250 workdays per year. He uses regional rail for commuting. He also travels 2 holiday trips to Thailand from Helsinki (7900 km/direction).

2 persons who travel more than average persons:

Person 5: Person works as a sales representative and therefore must travel a lot between Finland's towns and cities. He travels annually 50000 kilometers by auto.

Person 6: Person works in an international company and therefore must travel 1820 km/direction from Helsinki to London by plane once every two weeks. Lives in Helsinki and walks or uses bicycle for daily trips.

5 Analysis and results

5.1 Background information for analysis

5.1.1 Fuel consumption and emission amounts

The amount of greenhouse gas emissions each specific transport mode generates depends on many different attributes. The propulsion system, size of the vehicle and driving habits are some of these. Each fuel generates a specific amount of greenhouse gases in combustion. In the Table 11 below are listed the carbon dioxide generation and energy consumption in the process when burning a certain amount of different fuels.

Table 11. CO₂ and energy contents of different fuels (Motiva 2012, VTT 2012, Ministry of Transport and Communications 2012)

Emission contents		
Fuel	CO₂ content	Energy, MJ
Gasoline	2,35 kg/liter	32,25 MJ/liter
Diesel	2,66 kg/liter	36,335 MJ/liter
Natural Gas	2,75 kg/kg	49,1 MJ/kg
Electricity	240g/kWh	3,6 MJ/kwh
Kerosene (Jet A-1)	3,2 kg/kg	43 MJ/kg

The fuel consumption of certain vehicle types differs a lot. For private vehicles the fuel consumption numbers are quite well known. The problem is the amount of different car models and types which all have an own specific fuel consumption rate. In addition the different driving circumstances, age of the car fleet and the individual driving habits of drivers all take effect on the average consumption rates (VTT 2012). The average fuel consumption of different vehicle types is described in the Table 12 below. The numbers for diesel and gasoline vehicles are gathered from VTT: s Lipasto calculation system for traffic exhaust emissions and energy consumption in Finland. The numbers in Table 12 are average consumptions for the vehicle fleet in the year 2011.

In EKOtrafi service are listed the fuel consumptions of new hybrid vehicles, new PHEV vehicles and new natural gas powered vehicles available in Finland. In the hybrid vehicles the carbon dioxide emissions range from 49 g/km up to 219 g/km and include vehicles from normal sized cars up to large sedans and jeeps. In the comparison only average normal sized hybrid cars and natural gas cars are included to give the right picture of the greenhouse gas generation of a normal sized family car. The fuel consumptions are listed in the Table 12 below.

Table 12. Fuel consumption of autos. (VTT 2012, Trafi 2012)

Propulsion type	Urban	Highway	Combined
Gasoline	10,0 l/100km	6,6 l/100km	7,8 l/100km
Diesel	8,3 l/100km	5,4 l/100km	6,4 l/100km
Hybrid	4,1 l/100km	4,0 l/100km	4,1 l/100km
PHEV	2,1 l/100km	2,1 l/100km	2,1 l/100km
Natural gas	6,4 kg/100km	3,8 kg/100km	5,1 kg/100km

The fuel consumptions for mopeds and motorcycles in urban and highway driving is demonstrated in the Table 13 below. The numbers are average consumptions for the moped and motorcycle fleets in the year 2011 obtained from VTT:s Lipasto system.

Table 13. Fuel consumption of motorcycles and mopeds. (VTT 2012)

	Moped		Motorcycle	
	Urban	Highway	Urban	Highway
Gasoline	2,1 l/100km	-	3,3 l/100km	3,8 l/100km

There are three types of buses included to the analysis. These buses are diesel powered intercity bus which has the capacity of 50 passengers. The urban buses are diesel and natural gas powered and both of them can carry 80 passengers. These two types differ in some characters because they are designed for different traffic environments. Therefore the fuel consumption and greenhouse gas generation differs between these types (VTT 2012). In the Table 14 below are listed fuel consumption numbers for the bus types.

The fuel consumption between empty buses and fully loaded buses differs. The average urban and highway consumption numbers are average numbers of empty and full buses

which were gathered from VTT:s Lipasto charts. The consumptions are average consumptions for the bus fleet in the year 2011. The consumption numbers are listed in the Table 14 below.

Table 14. Fuel consumption of bus models. (VTT 2012)

	Urban bus		Intercity bus	
	Urban	Highway	Urban	Highway
Diesel	44,8 l/100km	-	43,5 l/100km	24 l/100km
Natural Gas	45,5 kg/100km	-	-	-

Examples of typical intercity and urban buses in use are shown in the following Figures 12 and 13. Figure 12 presents a typical 12 meter long low-floor Scania in use in Helsinki and Figure 13 presents a Scania OmniExpress which is widely used as a tourist bus or on operating intercity bus routes.



Figure 12. A typical 12 meter long low-floor Scania in Helsinki. (Scania 2012)



Figure 13. Scania OmniExpress intercity/tourist bus. (Scania 2012)

The electric train consumes electricity and the environmental effects and emissions are generated during the production of electricity. The energy consumption and greenhouse gas generation of electric trains can be calculated by the electricity consumption of a certain train and average emissions generated during electricity production (VR Group 2012). The average emissions generated in electricity production in Finland are shown in the Table 15 below. The numbers are 10-year averages. The primary energy factor takes into account the average efficiency of electricity production (50,8 %) and therefore the trains energy consumption is multiplied by the primary energy factor in order to find out the total energy consumption.

Table 15. Average electricity production emissions in Finland. (VTT 2012, Table 1)

Average emissions from electricity production in Finland (10-year average)	CO	HC	NO _x	PM	CH ₄	N ₂ O	SO ₂	CO ₂	Primary energy factor
g/kWh	0.157	0.016	0.375	0.044	0.008	0.007	0.273	240	1.97

In Figure 14 is a typically green and white colored SM4 train in Helsinki railway station, a train type which VR uses operating regional rail routes in the regional rail network.



Figure 14. SM4 regional rail train in Helsinki central railwaystation. (VR 2012)

In rail passenger transport the intercity trains included for comparison are Intercity electric train and Pendolino electric train and in regional/urban rail traffic the Sm4 electric train and the metro train. Figure 15 demonstrates a typical M200 metro train, a newer version of the two metro train types (M100 and M200) in use in Helsinki, operating in the Helsinki metro network. Figure 16 is a typical Pendolino train used in intercity rail traffic in Finland. The consumption of electricity as kWh/km of the four different train models is shown in Table 16.

Table 16. Electricity consumption of trains. (VTT 2012, HKL)

Train type	Intercity 2 train	Pendolino train	Urban Sm4 train	Metro
Electricity consumption kWh/km	11	12,5	5,9	3,3



Figure 15. M200-series metro train. (HKL 2012)



Figure 16. A typical VR Pendolino train. (VR 2012)

The fuel consumption of different airplanes differs a lot between different aircraft because of the technical differences and size of the aircraft. The fuel consumption varies a lot between the different flying situations, during take-off, cruising and landing (Ministry of Transport and Communications 2012). There are three types of airplanes with different operating distances included for the comparison. These example airplanes are a long distance jet Airbus A330-300, a medium distance jet Embraer 190 and a short distance turboprop ATR 72-500. The fuel consumptions of these airplanes are listed below in Table 17. The three different aircraft Airbus A330-300, Embraer 190 and ATR 72-500 included for comparison are demonstrated in Figures 17, 18 and 19.

Table 17. Kerosene (Jet A-1) consumption of different aircraft types. (Aircraftcompare 2012)

	Long distance jet, Airbus 330-300	Medium distance jet, Embraer 190	Short distance turboprop, ATR 72-500
Kerosene (Jet A-1)	0,11 km/litre	0,23 km/litre	0,43 km/litre

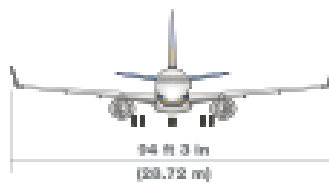


Figure 17. Embraer 190 medium distance turbofan. (Embraer 2012)

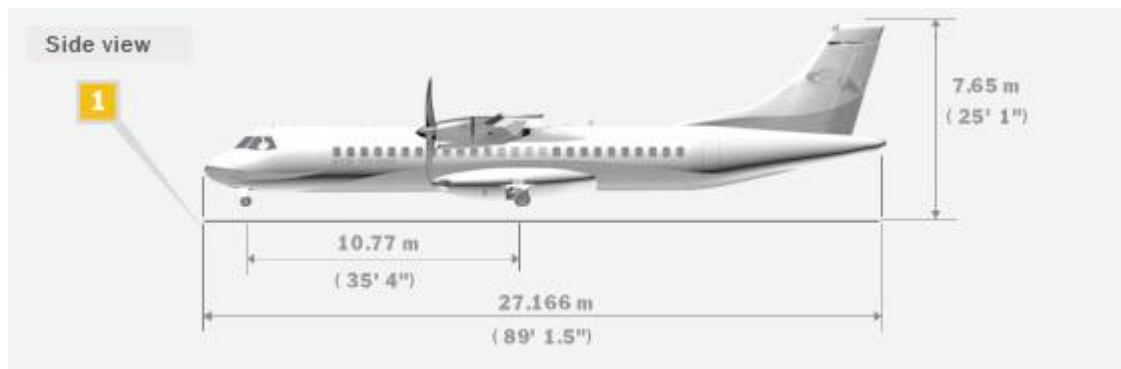


Figure 18. ATR-72-500 turboprop. (ATR 2012)

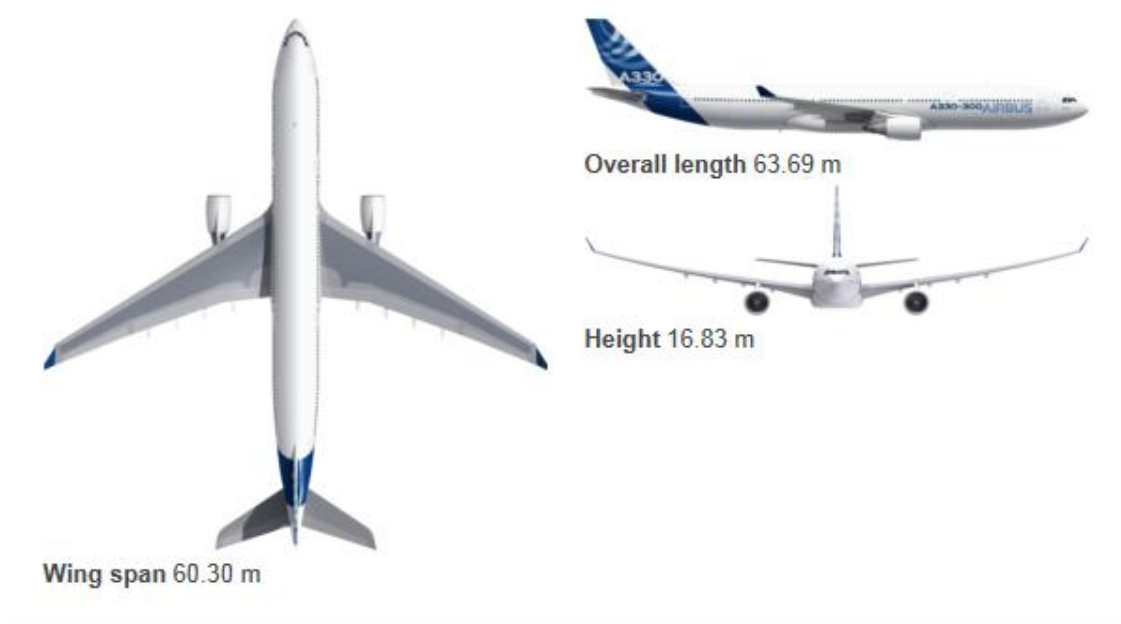


Figure 19. Airbus A330-300 long haul turbofan. (Airliners 2012)

5.1.2 Passenger capacities of modes

When comparing greenhouse gas generation per passenger for a certain trip length the passenger capacities of the vehicles and the average load factors in each situation must be known. The modal passenger capacities which are used to calculate the emissions and energy consumption per passenger for the different transport modes are listed in the following Table 18.

Table 18. Vehicle passenger loads. (VTT 2012, VR Group 2012, HKL 2012, Finnair 2012, Airbus 2012, Embraer 2012, ATR 2012)

	Max load of passengers (average)
Private car	5 (including driver)
Moped and motorcycle	2 (including driver)
Intercity bus	50
Urban bus	80
Intercity rail: Pendolino train	309
Intercity rail: Intercity 2 train	509
Regional rail: Sm4 train	184
Urban rail: Metro	287
Airplane: Turboprop	76 (ATR-72-500)
Airplane: Turbofan, long haul	297 (Airbus A330-300)
Airplane: Turbofan, medium/short distance	100 (Embraer 190)

5.1.3 Actual load factors

There is no specific information of modal load factors for different public transport modes in every situation and spatial context available. This is because there are many individual bus operators and the variation between different areas is related to the local conditions. For private vehicles the information of the actual amount of people travelling in a car in different trip situations is gathered for example in the The National Passenger Transport Survey. According to the survey the average amount of passengers in one vehicle is 1,1 persons/work related trip, 1,6 persons/school related trip, 1,7 persons/shopping related trip and 2,2 persons/leisure trip. When every different purpose trips are included the average passenger amount per vehicle is 1,7 passengers (Finnish Transport Agency 2012).

According to the Public transport performance statistics 2009 the average utilization rate in intercity buses was 18 % for long distance trips in the year 2007. In a normal intercity bus with a passenger capacity of 50 passengers the utilization rate of 18 % means 9 persons on board. According to (VTT 2012) the national average amount of passengers in an intercity bus route in Finland is 12 passengers in a bus.

In urban travel environment the average amount of passengers on board a bus is 18 (VTT 2012). According to the Public transport performance statistics 2009 the average utilization rate in urban buses in the year 2007 was 28 % for available seat kilometers and 18% in total (standing room included). In a normal urban bus with a passenger capacity of 80 passengers the foregoing utilization rates mean 22,4 and 14,4 passengers per vehicle.

Temporal variation of the amount of passengers in public transport vehicles varies a lot between different daytimes. In Turku city the amount of passengers in every bus line were calculated in March 2009. The bus lines were divided into normal bus routes, weekend night routes, school bus routes, service routes for elderly people and commuter routes. When a day is divided into 5 periods the average temporal variation of passengers per vehicle can be demonstrated. The numbers are shown in the Table 19 below.

Table 19. March 2009 average passenger amounts per bus line in Turku. (Korte 2012)

	School bus routes	Normal routes	Commuter routes	Service routes	Weekend night routes	Average
Morning 6-10	38,2	24,9	29,9	15,1	-	27
Day 10-14	24,0	33,4	-	21,7	-	26
Afternoon 14-18	27,7	36,2	17,0	14,7	-	24
Evening 18-22	-	23,1	-	-	-	23
Night 22-06	-	9,6	15,5	-	23,3	13

As the Table 19 shows, the passenger amount is highest in the morning and afternoon periods mostly because commuter travelling. During those periods there is also more bus capacity available. During night and evening time the amount of passengers is much lower and there are fewer buses operating. The average load factors increase with city size and therefore the numbers can vary between cities.

In urban rail traffic the utilization rate is 36 % of the total capacity in urban trains and 21 % of the total capacity in metro. In intercity rail traffic the total utilization rate is 30 % of the total capacity (Kanninen et. al. 2011). According to VTT: s LIPASTO calculation system the utilization rates for urban rail traffic is 35 % and for intercity rail traffic

35-40 % of the total capacity. The specific data of temporal variation of passengers on board is not easily available for every transport mode in different areas and trip situations. A conclusion can be made that the daily temporal variation in passenger amounts in other urban travel modes such as metro and regional rail follow the same pattern as the example numbers from Turku city show.

For airplanes the passenger amounts per airplane varies a lot depending on the season and flight type. In practice the average passenger load ranges between 50-80 %. The short domestic regular flights carry far less passengers than the longer international regular flights. In the long vacation charter flights the passenger capacity is normally almost fully used (VTT 2012). When examining the temporal variation of passenger amounts in regular flights the most passengers fly during morning or afternoon hours and during these periods the passenger capacity of aircrafts is used more effectively. The evening and night hours are much quieter and the airplanes are carrying fewer passengers (Merivirta 2012). The average utilization rate on flights is 60 % of available capacity (Kanninen et. al. 2011).

5.2 Results

5.2.1 Full vehicles

The CO₂ emissions were calculated for a theoretical situation where every transport mode has all of the available passenger capacity in use. In the Figure 20 below is shown the CO₂ amounts g/passenger km in urban traffic with full vehicles.

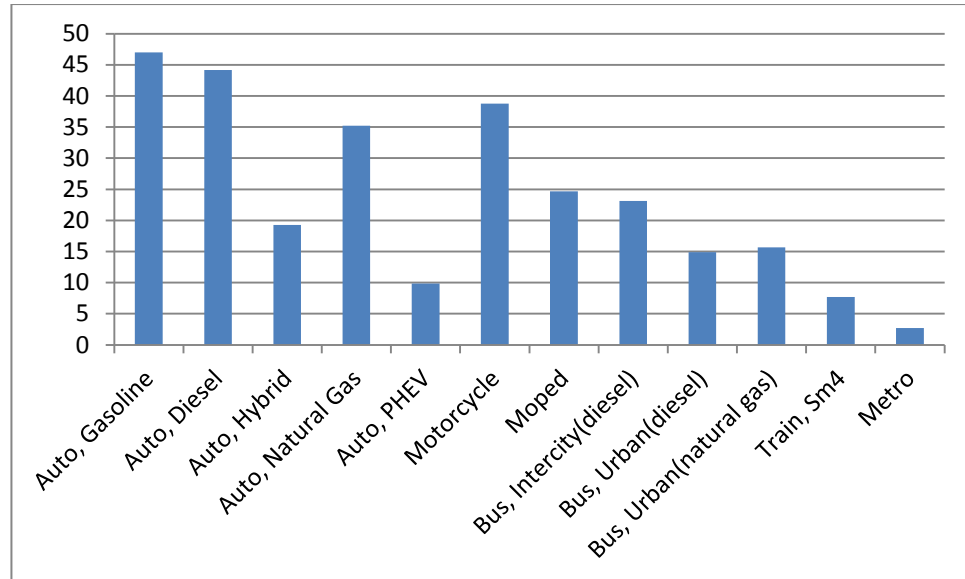


Figure 20. CO₂/passenger km in urban travel (Fully loaded).

The emission calculation for fully loaded vehicles show that the electric rail modes generate less CO₂ and consume less energy than any other mode, as Figure 20 shows. The hybrid and PHEV vehicles generate much less CO₂/passenger km in urban environment than gasoline and diesel vehicles. The fully loaded hybrid vehicle generates less CO₂/passenger km than a full intercity bus operating in urban traffic and the PHEV even less than any fully loaded bus included for comparison. The energy consumption MJ/passenger km of fully loaded vehicles is shown in Figure 21.

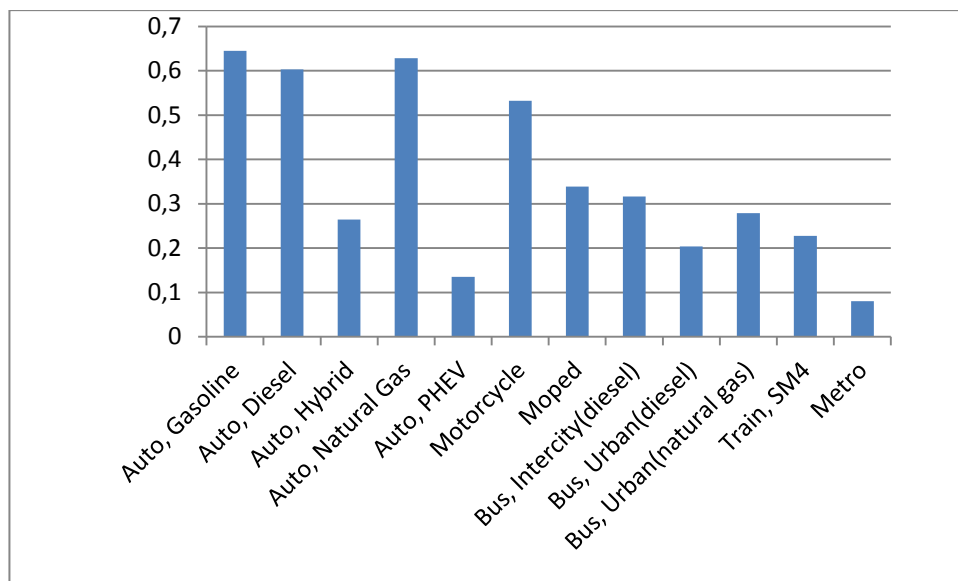


Figure 21. Consumed energy (MJ/person km) in urban travel (Fully loaded).

The emission calculation for fully loaded vehicles show that the electric rail modes generate less CO₂ and consume less energy than any other mode, as Figure 22 shows. Airplanes consume the most energy and generate also the most emissions.

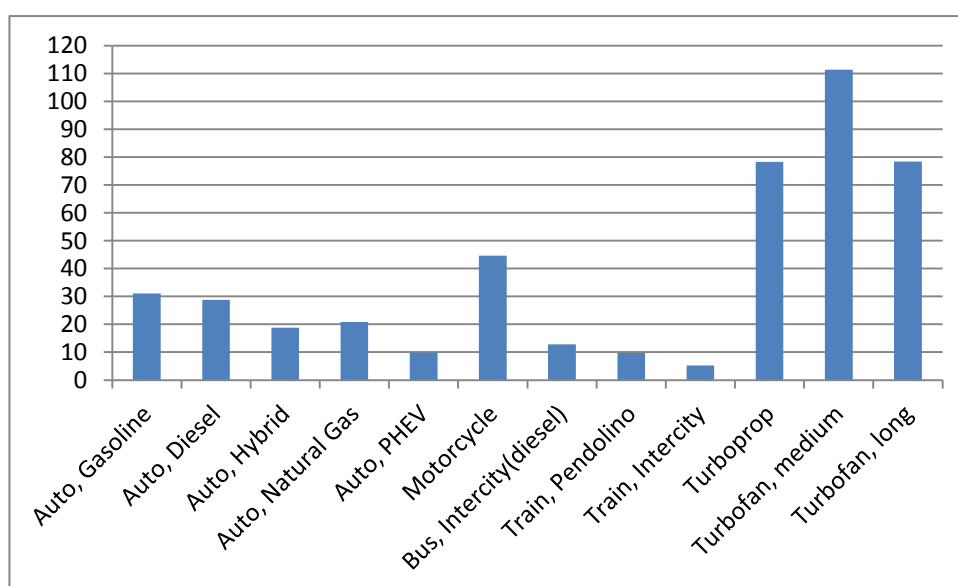


Figure 22. CO₂/passenger km in highway/long distance travel (Fully loaded).

As it can be seen from Figures 22 and 23 both full turboprop and full turbofan airplanes generate much more CO₂ emissions/passenger km and consume more energy than any other fully loaded vehicle. As it can be seen the full PHEV (5 persons), gets better results than a full diesel intercity bus. The fully loaded PHEV gets quite close to the emissions of a full Pendolino train. A motorcycle has quite high emissions per person com-

pared to the other private vehicles because their engines are inefficient compared to cars. The energy consumption MJ/passenger km of fully loaded vehicles is shown in Figure 23 below.

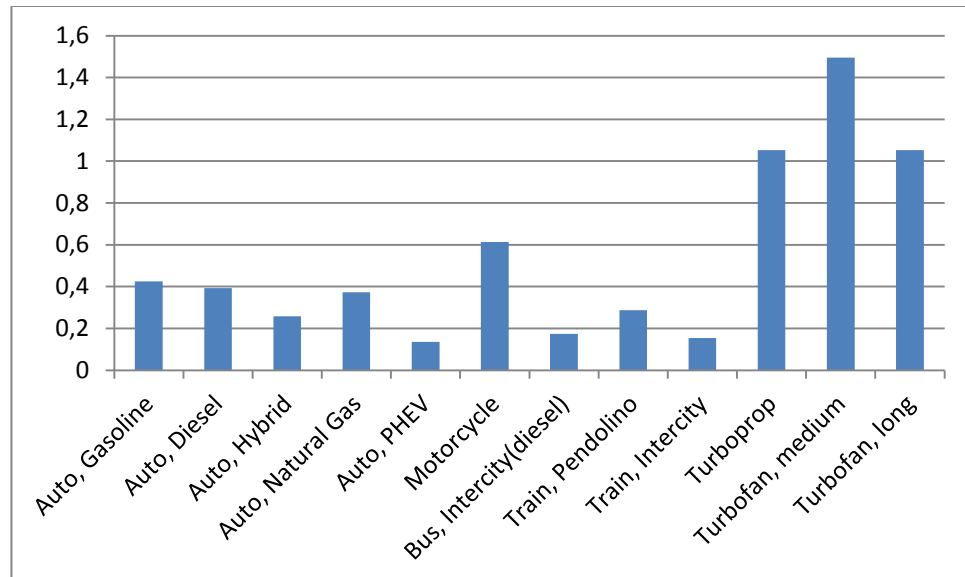


Figure 23. Consumed energy (MJ/person km) in highway/long distance travel (Fully loaded).

5.2.2 Very long distance travelling

When realistic modal load factors are taken into account the results are quite different. In very long distance travel the different types of aircraft are compared with autos carrying 1, 2 or 5 persons on board and motorcycle carrying 1 and 2 persons. The results are shown in the Figure 24. As it can be seen when the autos are carrying two or more passengers, the generated CO₂/person can compete with the full aircraft but off course when the travelled distance lengthens to intercontinental distances, the autos or motorcycle are no longer realistic choices.

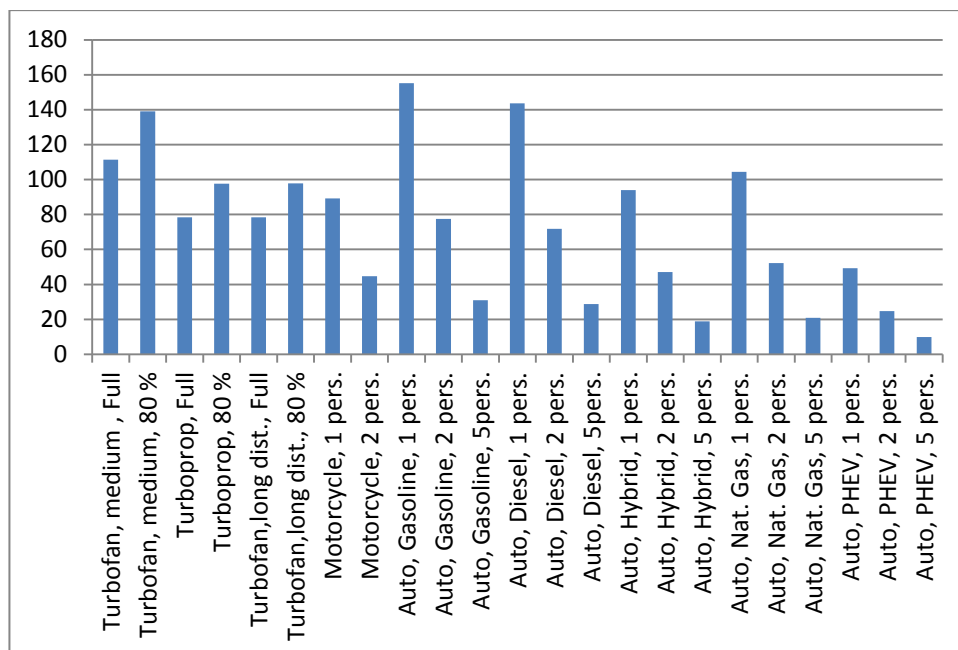


Figure 24. Generated CO2 (g/person km) in very long distance travel.

5.2.3 Long distance travelling

The long distance travelling in Finland was calculated separately for work trips and holiday trips using specific average load factors in private cars for each situation. In both situations the Intercity and Pendolino trains generated far less CO2 emissions than any other public transport modes and private vehicles with the load factors 1,1 and 2,2. The results of emissions per passenger generated in work trips with the average of 1,1 persons in a vehicle are shown in the Figure 25 below.

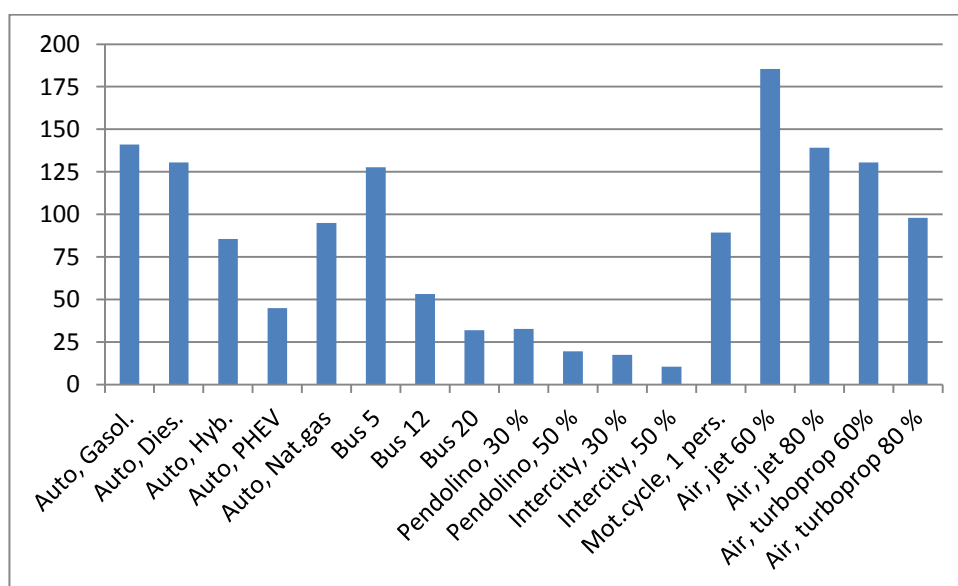


Figure 25. Generated CO2 (g/person km) in long distance work trips.

During work trips with fewer people on board in private cars the private vehicle CO₂/passenger km emissions are relatively higher and only PHEV vehicle can compete with the bus carrying a number of passengers over the average intercity bus amount 12 as the Figure 25 shows. The turboprop which is carrying the average domestic flight 60% of its passenger capacity has quite the same CO₂ emissions per passenger km than the diesel vehicle. If the passenger amount in the turboprop is less than the average 60 % of the capacity the diesel vehicle becomes quickly relatively less emitting than the turboprop engine aircraft. All of the private vehicles have less CO₂/passenger km emissions than the medium distance jet engine aircraft.

The generated CO₂ emissions per passenger on holiday trips with the average of 2,2 persons and 4 persons in a vehicle are shown in the Figure 26 below and compared to other modes. As it can be seen that with private vehicle load 2,2 compared to the average amount of 9 passengers in a intercity bus makes all of the private vehicles generate less CO₂ emissions per passenger than a bus. In the situations where the buses passenger count is higher than average the bus generates less CO₂ than most of the private vehicles. For example with the load of 15 passengers in a bus PHEV and hybrid vehicles are the only ones with less CO₂ emissions. The PHEV generates less CO₂ emissions per passenger even when the buses passenger count is 28 passengers.

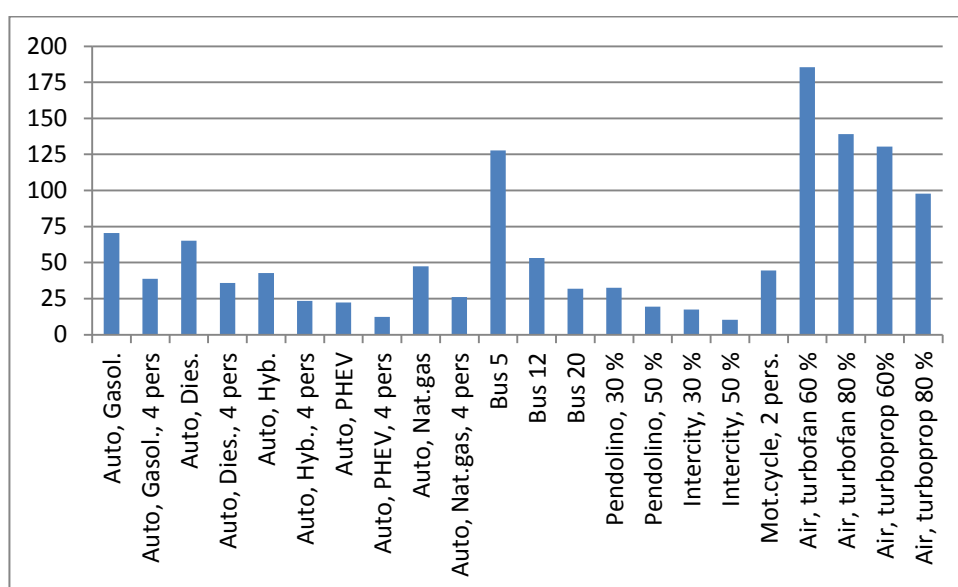


Figure 26. Generated CO₂ (g/person km) with 2,2 and 4 passengers per vehicle.

The Figure 26 shows also that if there is a 4 person family travelling in any of the private cars the amount of CO₂/passenger km drops below the intercity buses amount of CO₂/passenger km with intercity bus average of 12 passengers on board. The hybrid and PHEV with 4 passengers can compete also with the Pendolino using the national average 30 % of its passenger capacity.

The total CO₂ generation in long distance holiday trips (2,2 persons/auto) relative to the different travelled distance is shown in the Figure 27 below. It can be seen that as the travelled distance to the holiday destination rises, the differences between the generated CO₂ also grows.

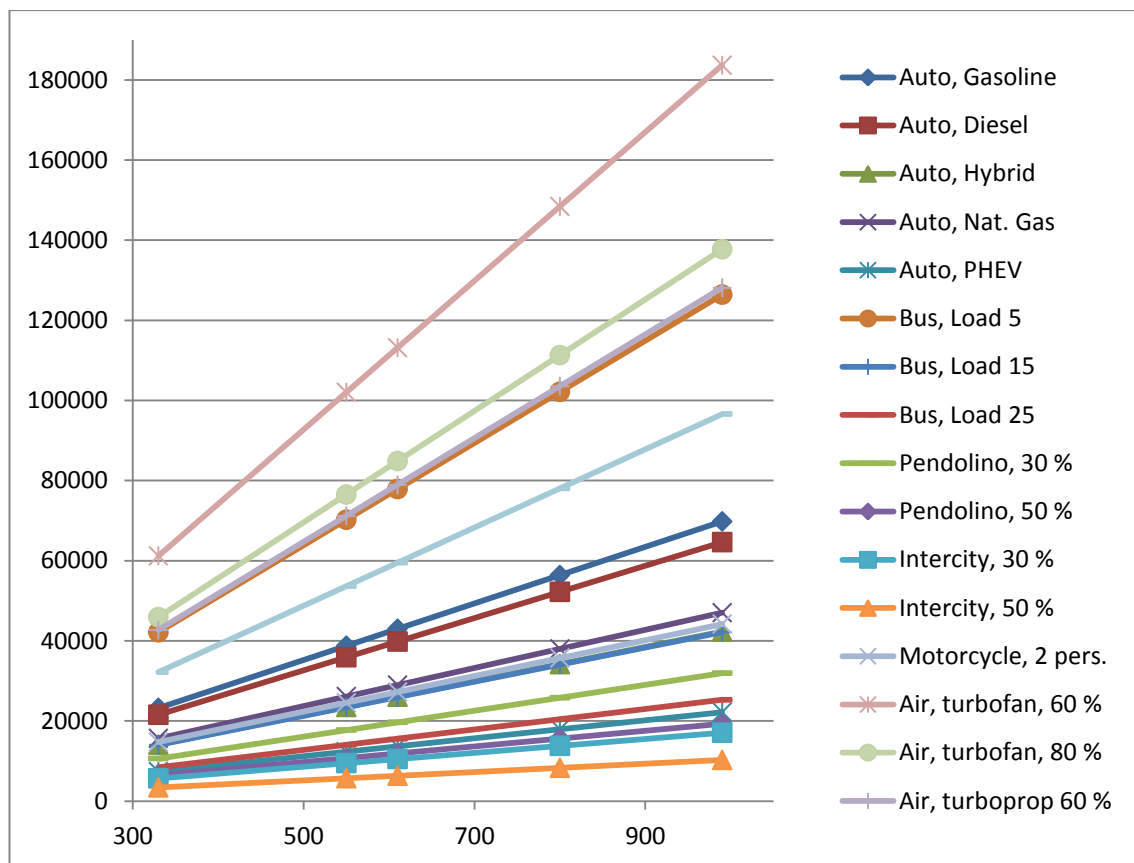


Figure 27. Trip length effect on generated CO₂ (g/person km) on 300-900 km long distance holiday trips.

The total energy consumption during long distance work trips (1,1 persons/auto) is shown in the Figure 28. When the Figure 27 and Figure 28 are compared together it can be noticed that a turbofan aircraft carrying a low domestic flight load of 60% of its capacity consumes energy and generates also the most CO₂ compared to other modes. On

work trips with only 1,1 persons/auto, the autos are no longer as energy efficient than on holiday trips with 2,2 persons/auto.

The curves for aircraft in both Figures 27 and 28 demonstrate results calculated for the average per distance fuel consumptions of aircraft and they do not include the fact that in reality the aircraft produces relatively higher emissions amounts and consumes more energy during take-off, landing or if the aircraft needs to circle around the airport before landing. As a result of this, the energy consumption and greenhouse gas generation is relatively higher especially on shorter flights. During shorter flights the actual travelled distance for an aircraft is longer and energy consumption and greenhouse gas generation raises because of the takeoff, landing and approach makes a bigger share of the total trip length (VTT 2012).

In Figures 27 and 28 the energy consumption and CO₂ generation curves for PHEV vehicles are based on the average per distance consumption amounts. It should be noticed that the PHEV vehicle per kilometer consumption varies based on the drive cycle and distance driven. The PHEV vehicles can drive the shortest trips (20-40 kilometers) by using only the charged electricity. After that the PHEV consumes fuel close to a regular hybrid vehicle (Gonder et. al. 2006). Therefore the CO₂ generation and energy consumption of PHEV vehicle is lower during shorter trips and all electric drive and rises when the combustion engine comes along. The same occurs also for the PHEV curves in the other trip situations demonstrated in the following Figures 28, 29, 30, 36, 37, 42 and 43.

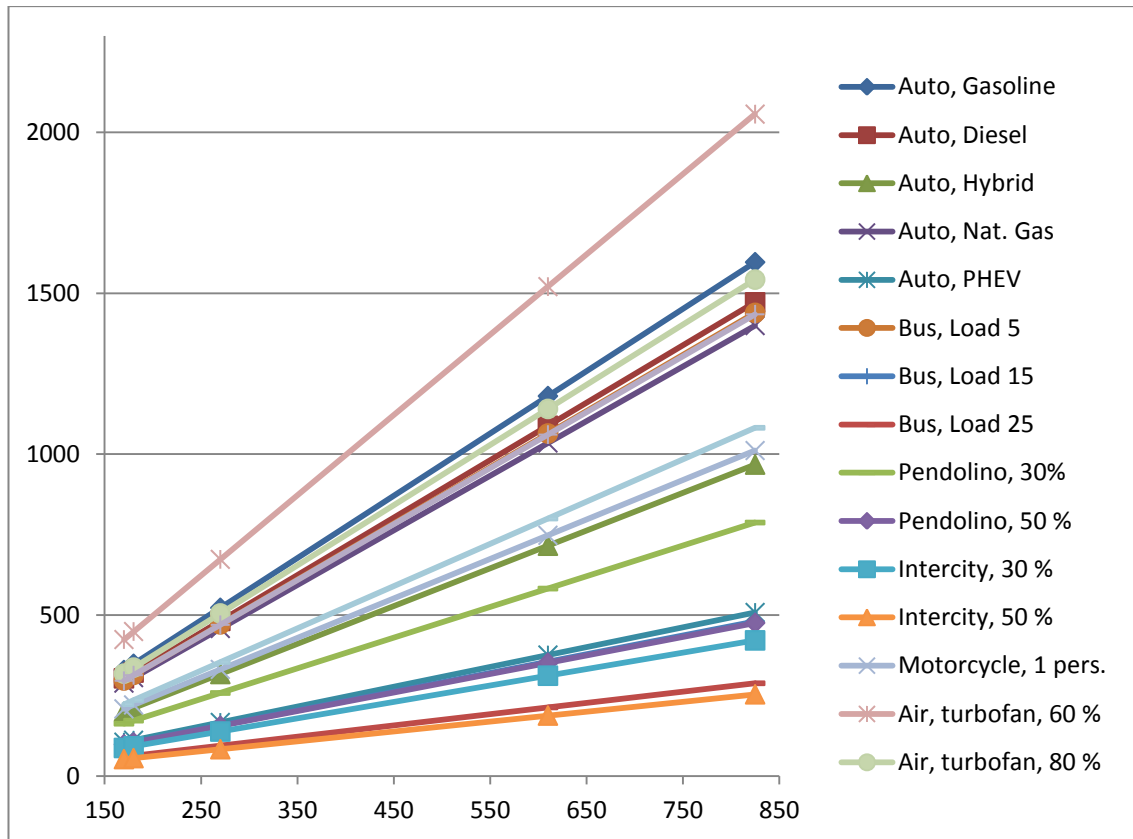


Figure 28. Trip length effect on consumed energy (MJ/person km) on 150-840 km long distance work trips.

5.2.4 Rural travelling

In rural environment travelling the calculated trip examples ranged from 10 km up to 100 km. The Figures 29 and 30 below show the trip lengths effect on the total amount of generated CO₂/passenger and consumed energy during shopping trips with the average of 1,7 persons/auto. The trip lengths are generally shorter in dense urban and small town travel environments while longer trips are generally required in rural areas even for the most routine parts of life. Even longer trips, of course, will be done even less frequently. The differences between the generated greenhouse gas amounts and energy consumption of different transport modes increase as the trip length increases as shown in the Figures 29 and 30. It can be noticed that the gap between the vehicles generating the most and less CO₂ increases as the travelled distance increases as the CO₂/passenger-km curves rise in different steepness. Note, for example if the load used for private vehicles is 1,7 persons, (the average load for rural shopping trips) the PHEV, natural gas and hybrid vehicles all have lower emissions than a bus with an average of 10 persons on board.

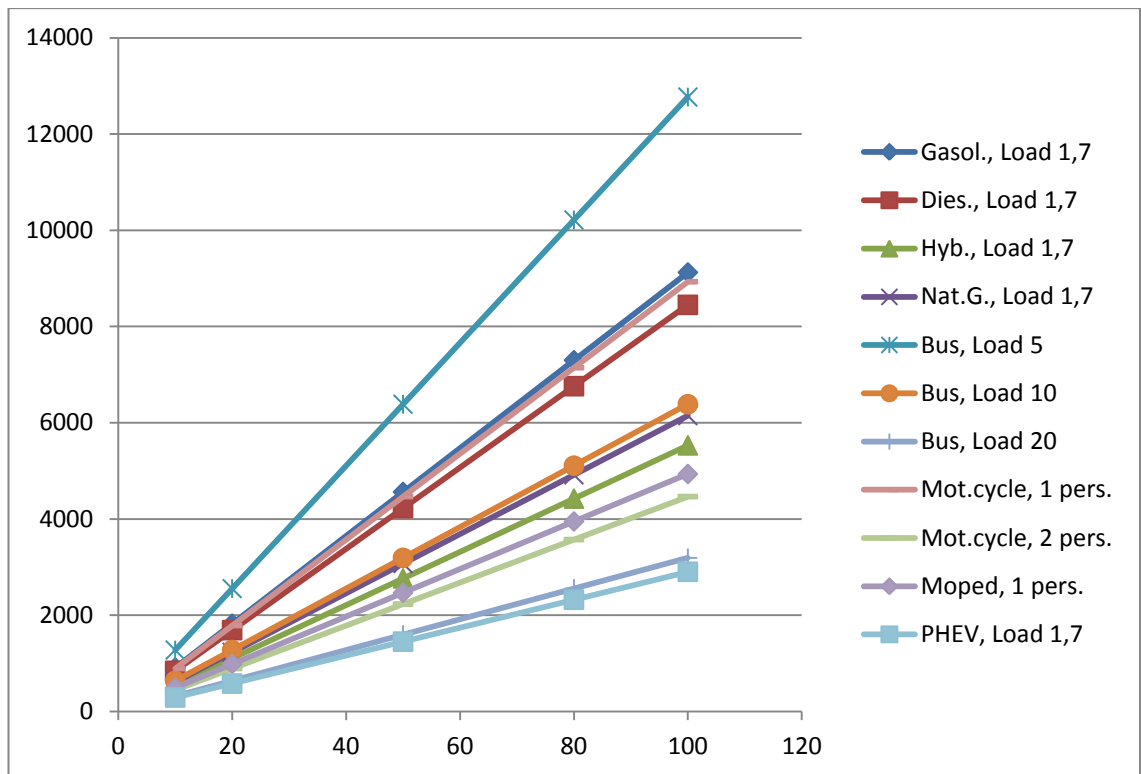


Figure 29. Trip length effect on generated CO2 (g/person km) on 10-100 km rural trips.

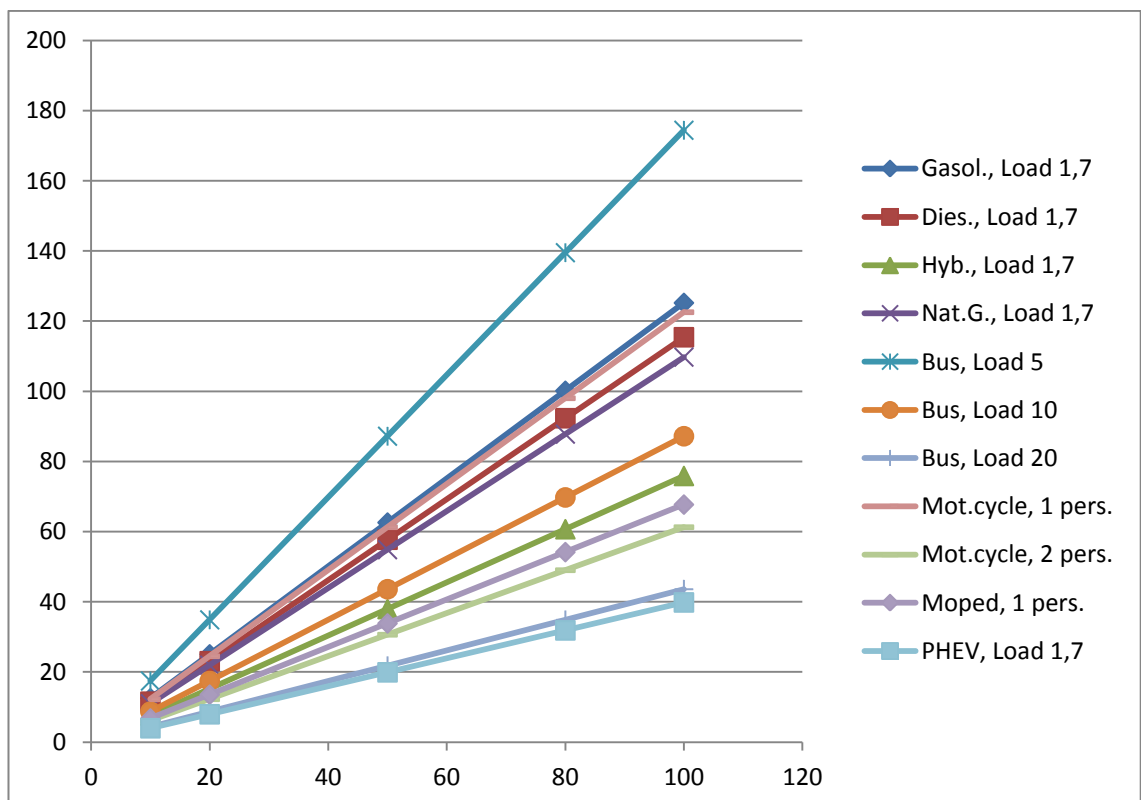


Figure 30. Trip length effect on consumed energy (MJ/person km) on 10-100 km rural trips.

In commuter travelling the private vehicles have the average of 1,1 persons in a vehicle. The calculation indicated that with this load the PHEV vehicle generates less than a bus with up to 14 passengers on board. The average rural utilization rate in a bus is 18 % (Kanninen et. al. 2011) which is approximately 9 passengers/bus. In the situation where the amount of passengers on a bus is less than average for example 5 passengers in a very quiet route all of the private vehicles except gasoline and diesel generate less CO₂ per person compared to the bus. Also moped and motorcycle with driver only generate less CO₂ per person km than a bus with 5 passengers on board. The results for CO₂ g/person km are shown in the Figure 31 below.

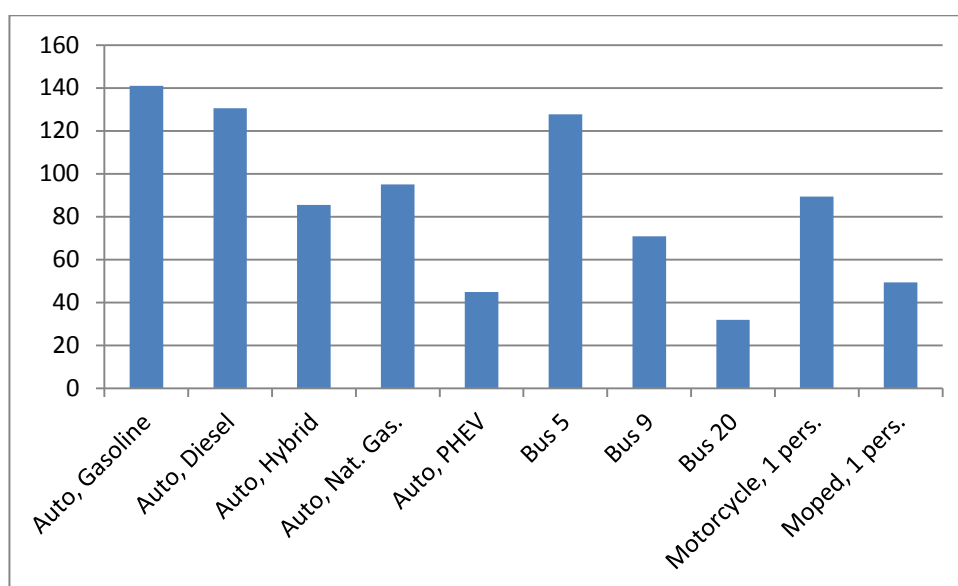


Figure 31. Generated CO₂ (g/person km) in rural commuter trips.

In shopping and school trips which were calculated separately the average passenger amount in private vehicles is almost the same in both situations: 1,7 passengers vs. 1,6 passengers. The results are shown in Figure 32.

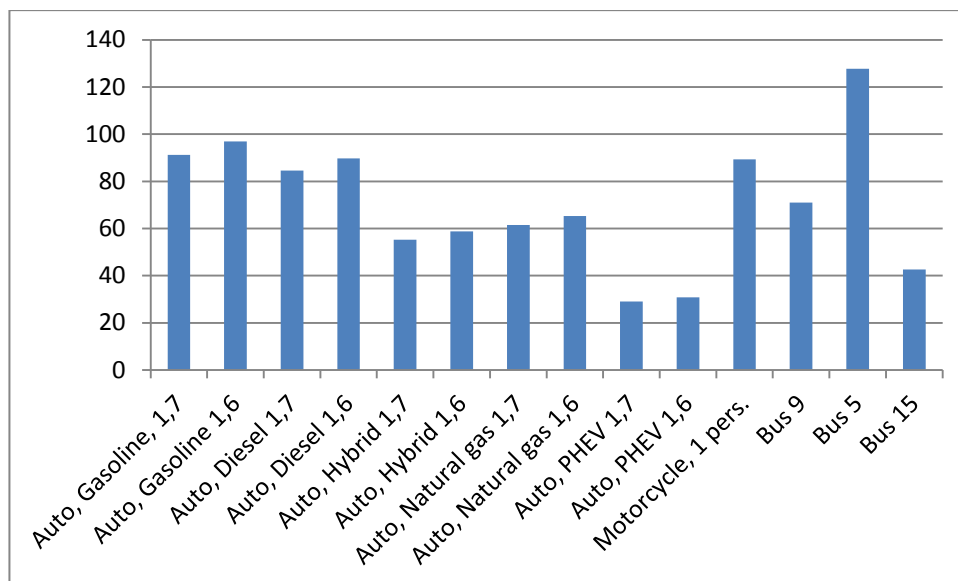


Figure 32. Generated CO2 (g/person km) in rural shopping and school trips.

As Figure 32 shows there is not much difference in the private vehicle CO2 amounts per passenger in those situations. When compared to the bus it can be noticed that with a passenger load 1,7 all private vehicles generate less CO2 per passenger than a bus with 7 passengers on board. In a situation where there are more passengers in a private vehicle for example a 4 person family there must be over 16 passengers in a bus to make it more environmentally friendly. This situation is demonstrated in Figure 33 below.

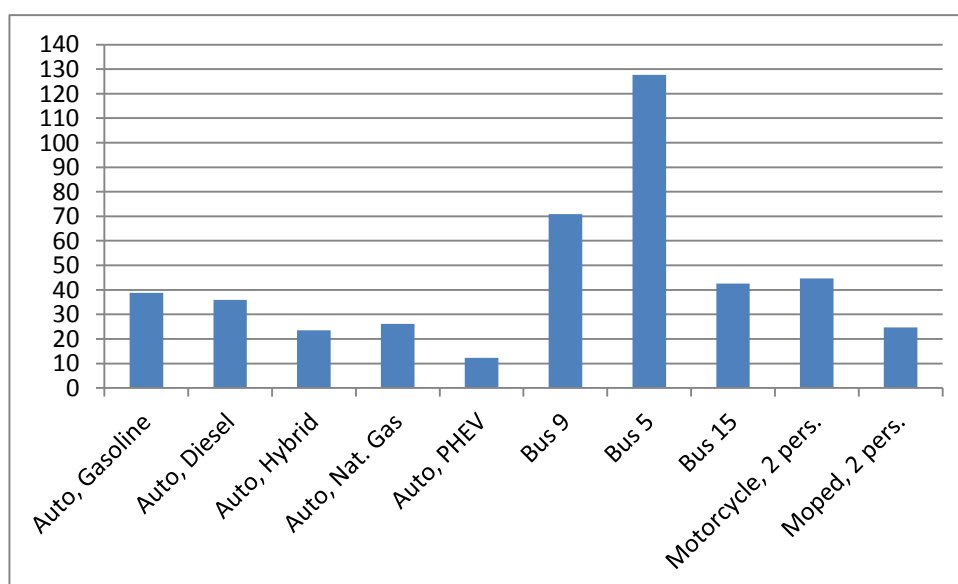


Figure 33. Generated CO2 (g/person km) in rural trips (4 persons in autos).

5.2.5 Small town trips

Small town transport in Finland relies mostly on private vehicles and buses and non-motorized travel. The results, which depend on the load factors, rank between the results for rural and dense urban travel. The calculation results for small town commuting, shopping and leisure trips, as shown in Figure 34 below, show private vehicles with average load 1,1 passengers for commuting, 1,7 passengers for shopping and 2,2 passengers for leisure trips. As can be seen the fuel consumption of vehicles in urban environment is higher than highway driving and therefore the generated CO2 amounts are also higher. The buses generated CO2 amounts between urban and highway driving grow relatively more compared to the autos CO2 generation in the urban environment.

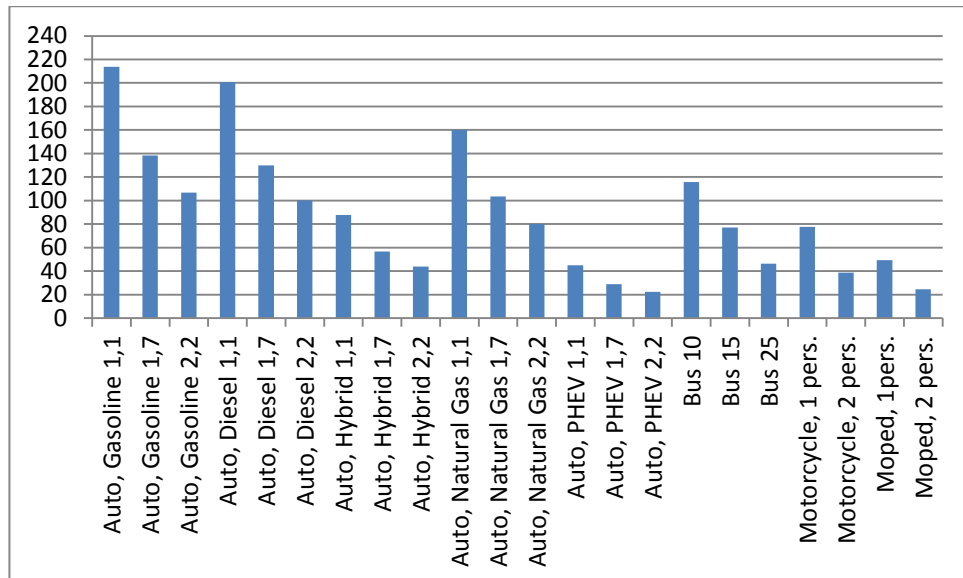


Figure 34. Generated CO2 (g/person km) in small town travel.

But whether urban or rural driving is a better approximation for a particular small town travel environment, it would depend on the particular small town. The average passenger number in a bus in small town environment is lower than in dense urban environment. With 15 passengers on board the bus, the generated CO2 emissions per passenger are lower than with 2,2 persons in private vehicles. Only the hybrid and PHEV vehicles generate less CO2 per passenger.

5.2.6 Commuting to nearby city

Commuting trips by highway to nearby city was calculated separately as an own trip group to show the effects of the number of passengers travelling in the same auto on the generated emissions and consumed energy. The calculation was done for autos with 1, 2 and 5 persons on board, motorcycle with 1 and 2 persons on board and the results were compared to intercity bus and regional rail with average passenger loads. The Figure 35 below shows the results for CO₂/person km in these different situations. As it can be seen the number of passengers in a private vehicle has notable effect on the generated CO₂/person km. When there is a full auto of commuters the CO₂ amounts/person km are relatively low. The commutation occurs usually during peak periods when buses are almost full and therefore the buses generated CO₂/person km is also relatively low compared to other vehicles. Notable is that a full PHEV vehicle generates even less CO₂/person km than a full bus. The travelled distances effect on the generated CO₂ and consumed energy amounts are shown in Figures 36 and 37.

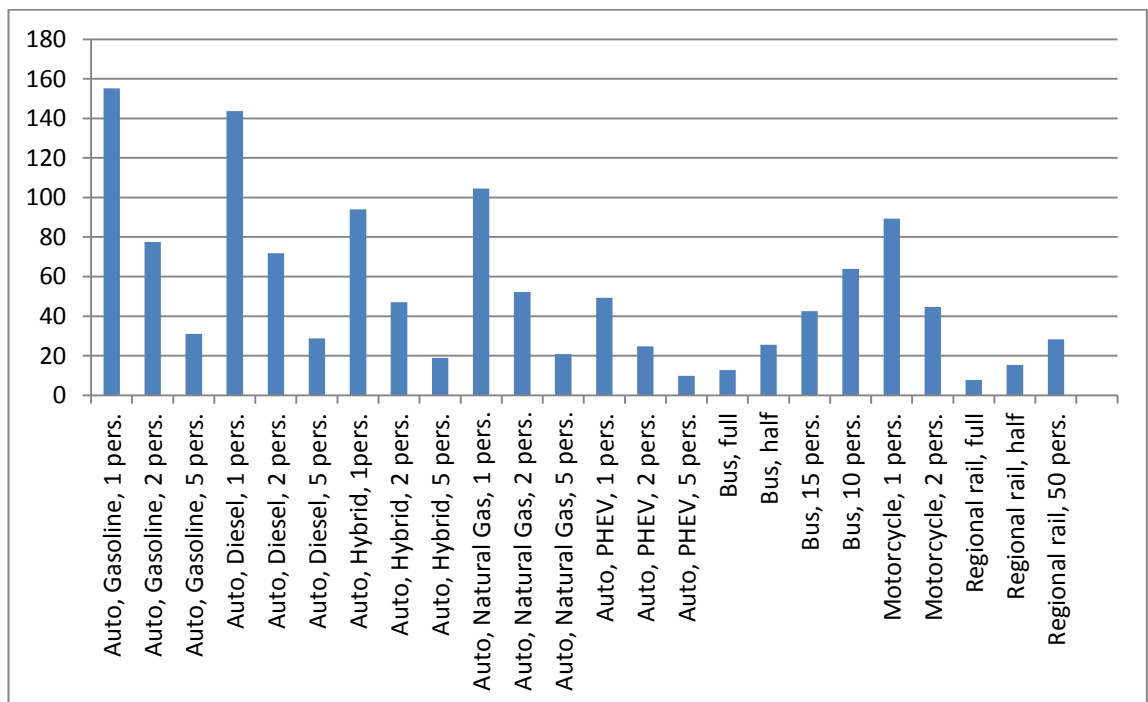


Figure 35. Generated CO₂ (g/person km) in intercity commuter travel.

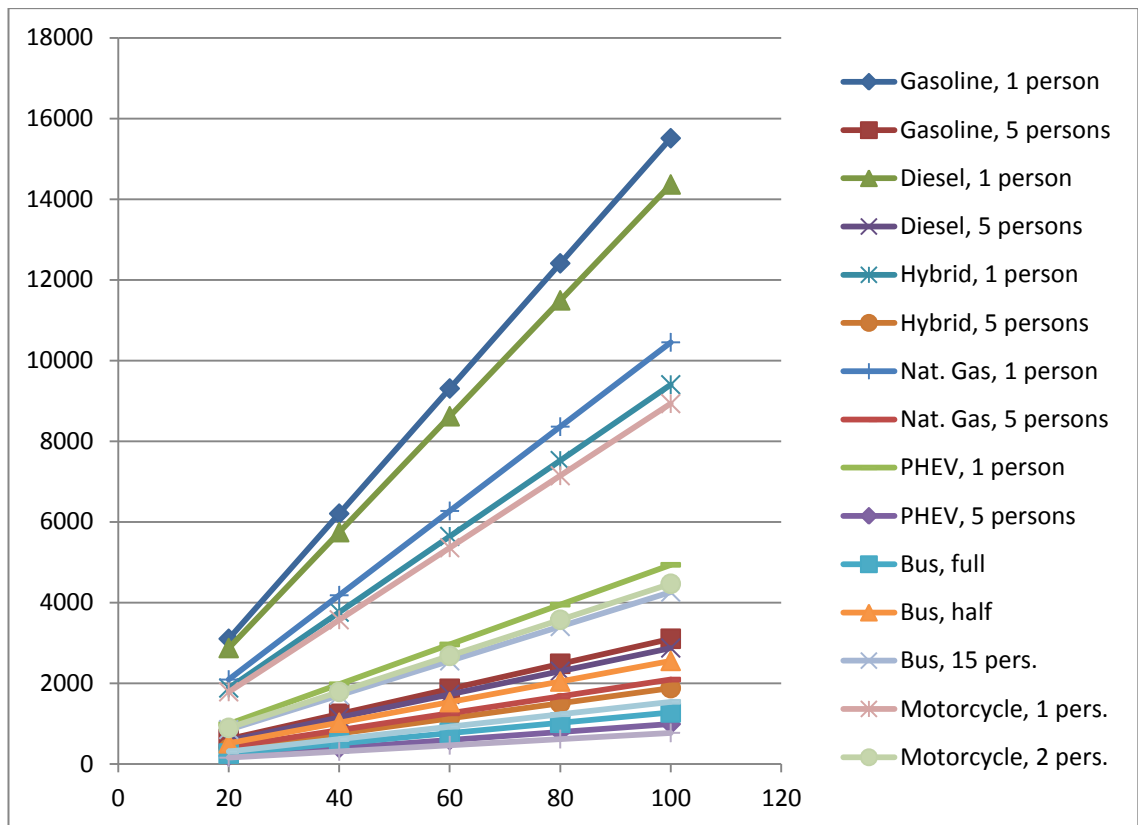


Figure 36. Trip length and generated CO2 (g/person km) on 20-100 km commuter trips.

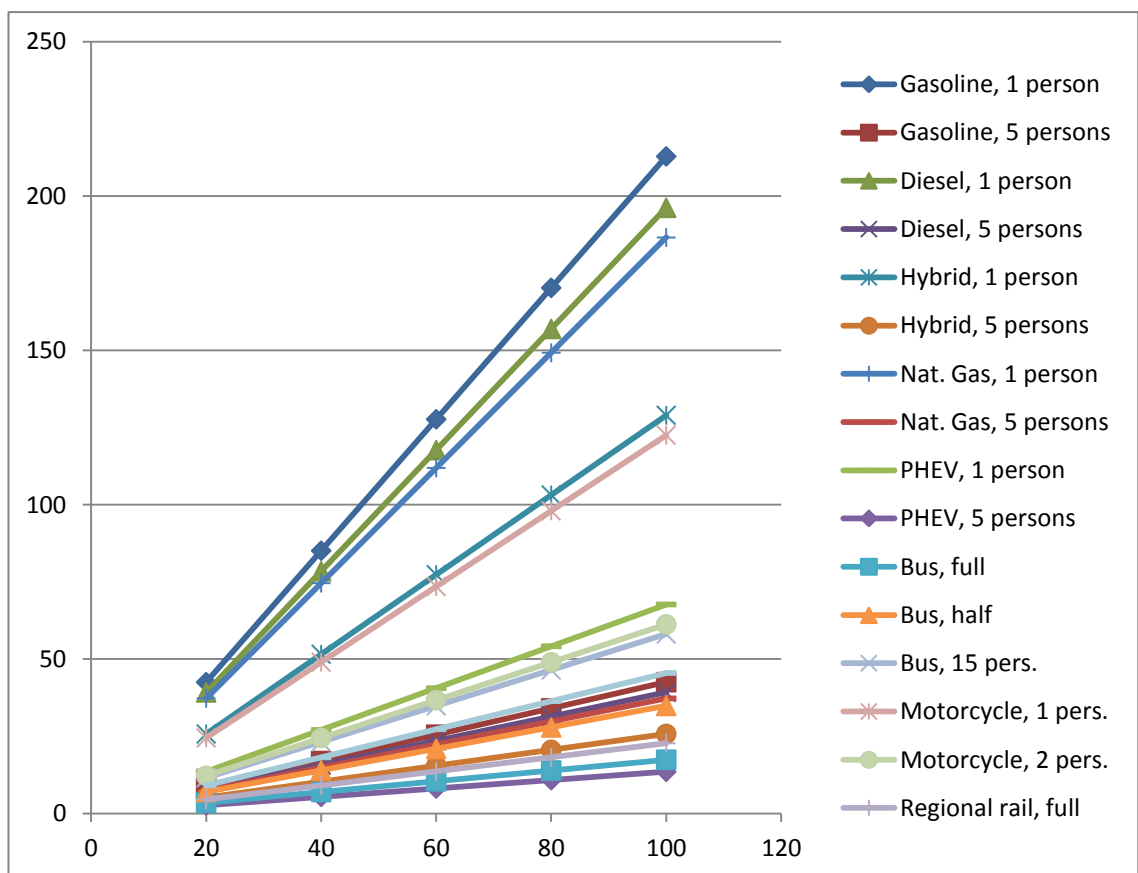


Figure 37. Trip length and consumed energy (MJ/person km) on 20-100 km commuter trips.

5.2.7 Dense urban trips

The dense urban environment trips were calculated separately for commuting, shopping, school and leisure trips and the different private vehicle load factors in each trip situation were used. When the dense urban environment is observed there are metro and regional rail in addition to buses. There are on average more passengers in public transport vehicles than in smaller towns or rural environment although the amounts vary sharply between peak and off peak periods. In the Figure 38 below is shown the results for commuting in dense urban environment. As it can be seen the regional train SM4 and metro are generating less CO₂/passenger km even with smaller passenger loads. The PHEV can compete with both of the buses with different loads and generates less CO₂/passenger km than any bus with the dense urban environment passenger loads used in the comparison. The hybrid vehicle generates less than both of the buses packed with the relatively low night time load of 13 passengers on board.

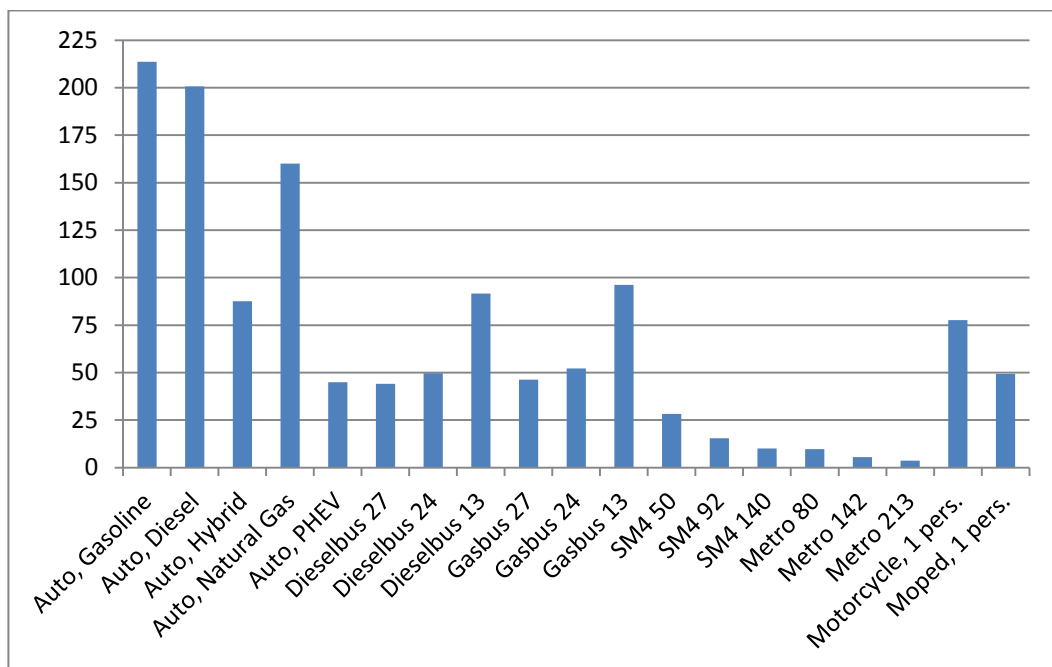


Figure 38. Generated CO₂ (g/person km) in dense urban environment commuting.

When average shopping trip loads are used the gaps between the private vehicle relative CO₂ generation/passenger and the buses generation get smaller. The natural gas vehicle with average load 1,7 gets quite close to the buses with 13 passengers on board. The results can be seen in the Figure 39 below.

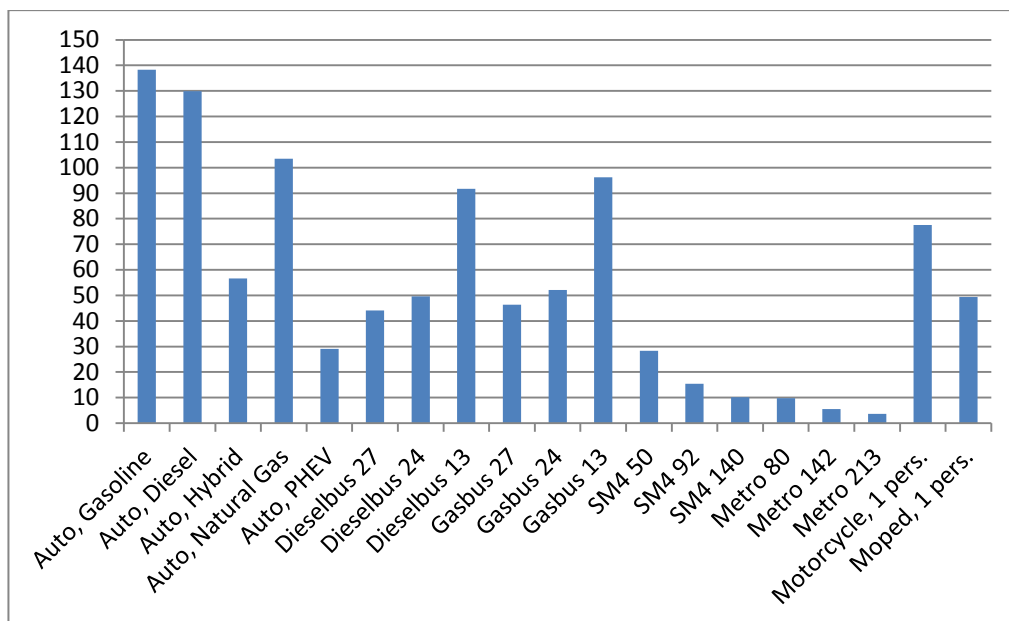


Figure 39. Generated CO2 (g/person km) in dense urban environment shopping trips.

The Figure 40 below demonstrates the results for dense urban area school travelling. The results for school trips are quite the same with the results of shopping trips demonstrated in the Figure 39 above when the Figures are compared together.

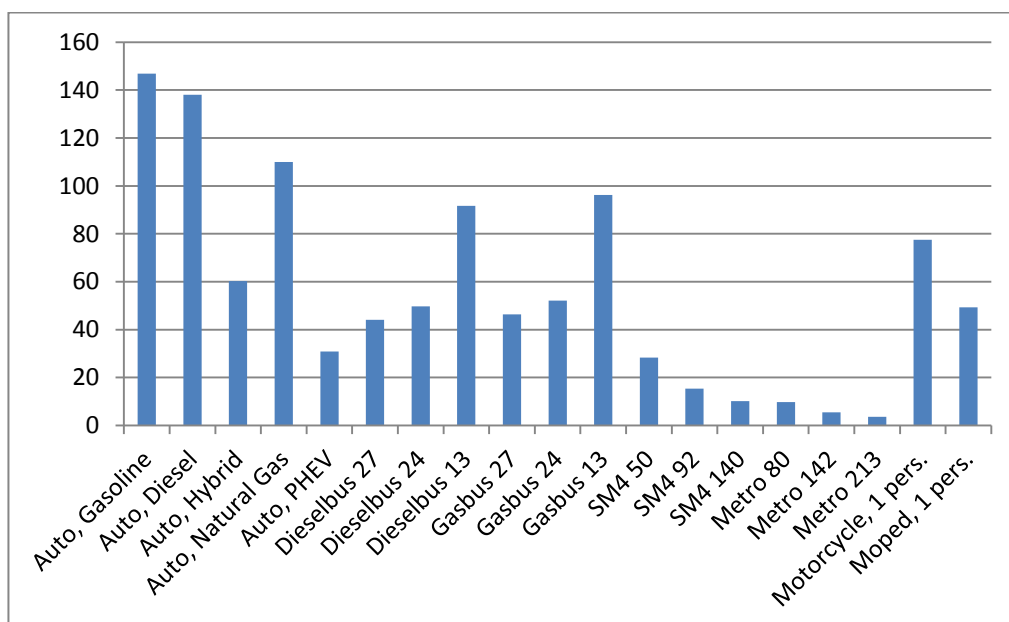


Figure 40. Generated CO2 (g/person km) in dense urban environment school trips.

The results for dense urban area leisure trips with the average load of 2,2 persons in private cars are shown in the Figure 41 below. As it can be seen the hybrid and PHEV

vehicles both generate less CO₂/passenger km than any of the buses loaded with average dense urban passenger amounts.

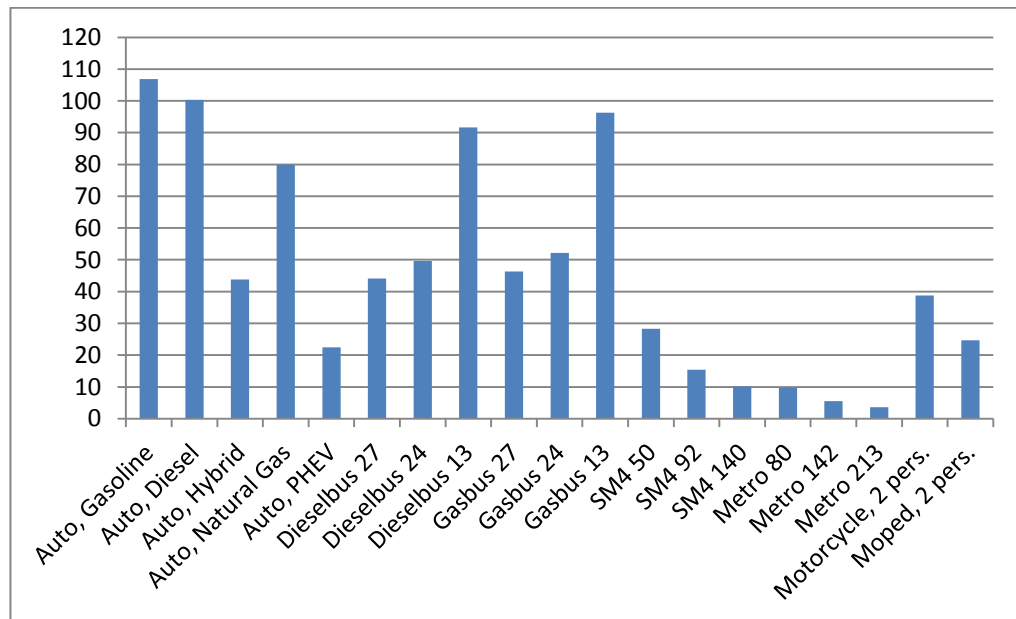


Figure 41. Generated CO₂ (g/person km) in dense urban environment leisure trips.

The Figure 41 also shows that with the 2,2 person amount in private vehicles the natural gas car generates less CO₂/passenger km than the buses during night time passenger amount 13 persons on board. The diesel car gets quite close with the natural gas bus with 13 passengers.

The Figure 42 shows the results for CO₂ per passenger when the average 2,2 leisure trip load is used in private vehicles. The metro and regional rails consume less energy and generate less CO₂ than the other modes. When the buses carry the average morning load of 27 passengers, only the PHEV generates less CO₂ and the hybrid has about the same CO₂ amounts per passenger compared to the buses. When the buses carry an average night load of 13 passengers, it can be seen that the generated CO₂ amounts per passenger rise significantly. The Figure 43 demonstrates the consumed energy amounts relative to the travelled distance.

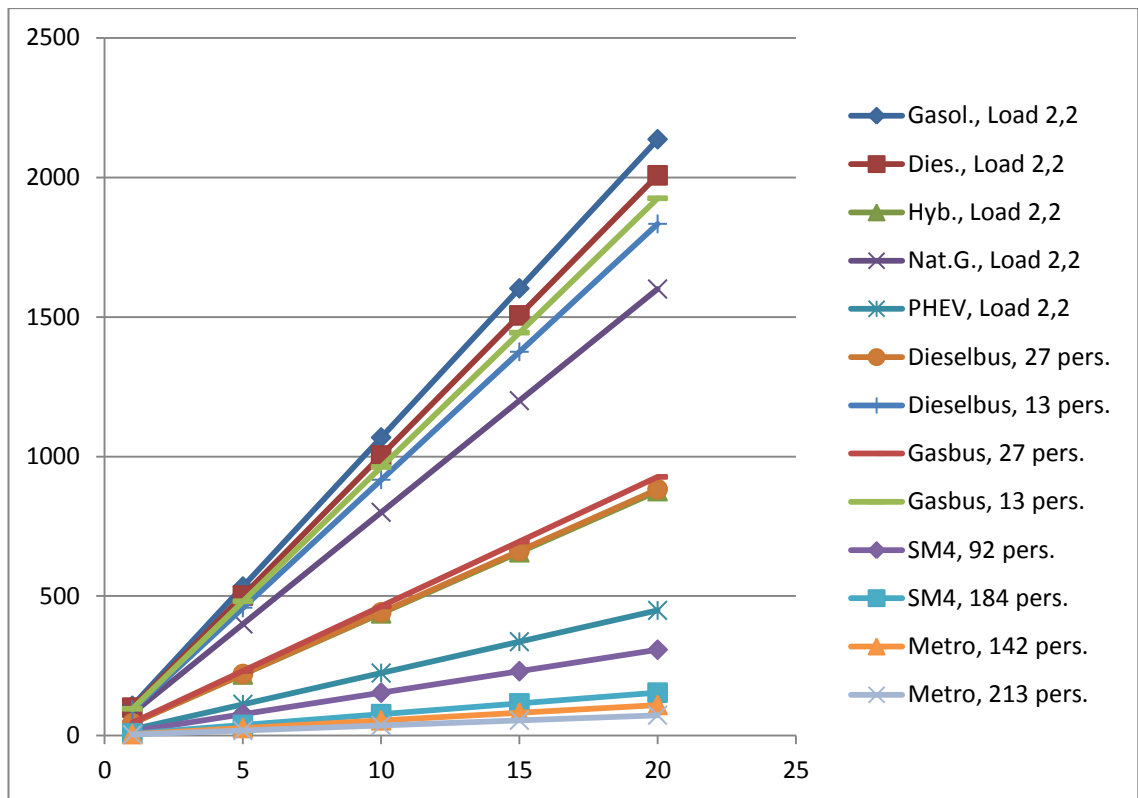


Figure 42. Trip length effect on generated CO2/person on 1-20 km dense urban trips.

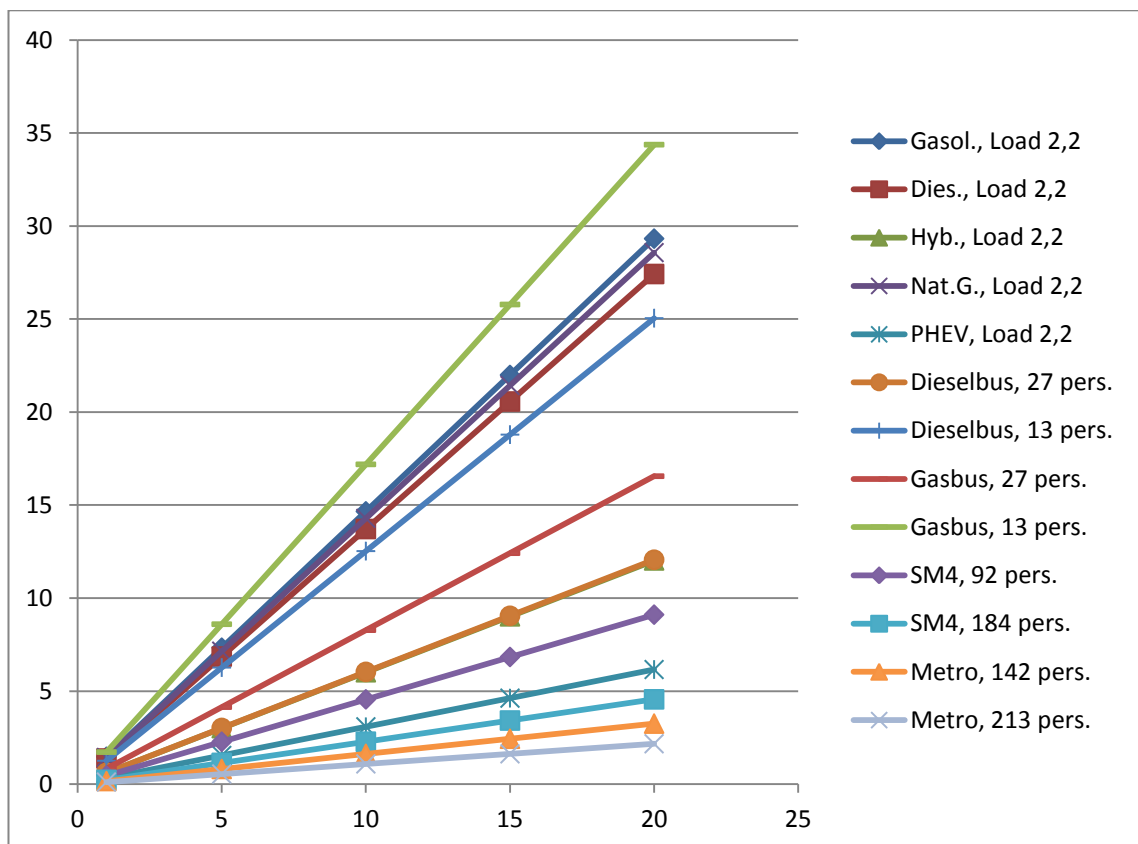


Figure 43. Trip length effect on consumed energy (MJ/person km) on 1-20 km dense urban trips.

5.2.8 Case study

When assessing the “carbon footprint”, that is, the annual total CO₂ generation of individuals with different travelling habits must be summed. The following Tables 20, 21, 22, 23, 24 and 25 shows six (6) hypothetical but highly realistic types of person. Persons 1 and 2 both live in the same rural area but their travel behavior and travelled distances differ. Person 1 drives a car 50 km once a week to shop but works at home, while person 2 commutes 30 km daily by rural bus. Persons 3 and 4 live in the same urban area but there is a difference in their travel behavior as well. Person 3 commutes by 5 km by auto each workday and travels four times per year to a summer cottage. Person 4 commutes 5 km each workday by regional rail but also travels abroad on very long distance travel twice per year. Person 5 travels a high amount annually by auto. Person 6 flies once every two weeks 1820 km/direction from Helsinki to London by plane but walks or uses bicycle for daily trips.

It can be seen that Persons 3 and 4 living in the urban area travels short distances for their daily commute compared to persons 1 and 2 but both urban residents (Persons 3 and 4) have larger carbon footprints than the rural residents (Persons 1 and 2). In particular, person 4’s footprint is very much higher due to the 2 annual very long distance flights. Furthermore, Person 2 who commutes daily 30 km by rural bus, compared to person 1 who drives a car a longer distance of 50 km but only once per week, creates about the same carbon footprint. If Person 1 uses hybrid or PHEV, the carbon footprint is notably smaller.

When Persons 5 and 6 are compared to the other persons it can be noticed that if the annual travelled distances are higher than average, for example for individuals who must travel business trips around the country by auto or to fly to another country often, the generated CO₂ amounts are notably higher as the results show. The vehicle size and propulsion type have notable effects on the energy consumption and greenhouse gas generation. Especially when the annual travelled distances are high as the results of Person 5 show, individuals can lower their carbon footprint notably by choosing a more eco-friendly auto such as PHEV or hybrid.

Person 1: Lives in a rural area. Person travels once per week 50 km for shopping by car. He works at home so he does not have to commute to work.

Table 20. Person 1's annual CO₂ production.

Rural Person 1: Drives a car once per week 50 km for shopping, but works at home.					
	Annual CO ₂ generated, kg, (1 person/auto)				
Annual distance travelled	Gasoline	Diesel	Hybrid	PHEV	Gas
2600 km (highway)	403	374	244	127	273

Person 2: Lives in rural area. He does not own a private vehicle and therefore uses public transportation and travels approximately 30 kilometers per day by bus on 250 workdays per year.

Table 21. Person 2's annual CO₂ production.

Rural Person 2: Commutes by bus 30 km/day on 250 workdays.					
	Annual CO ₂ generated, kg, (Average load in bus 12 persons)				
Annual distance travelled		Diesel			
7500 km (highway)		398			

Person 3: Lives in urban area and commutes 5 km per day on 250 workdays per year. He uses auto for commuting and also travels 4 trips per year to a summer cottage (200 km/trip).

Table 22. Person 3's annual CO₂ production.

Urban Person 3: Commutes 5 km/day on 250 workdays by auto in urban environment and travels 4 trips to summercottage (200 km/trip).					
	Annual CO ₂ generated, kg, (1,1 persons/auto during commuting and 2,2 persons/auto during holigay trip)				
Annual distance travelled	Gasoline	Diesel	Hybrid	PHEV	Gas
1250 km (urban)	267	250	109	56	200
3200 km (highway)	225	209	137	71	153
Total	493	459	246	127	353

Person 4: Lives in urban area and commutes 5 km per day on 250 workdays per year. He uses regional rail for commuting. He also travels 2 holiday trips to Thailand from Helsinki (7900 km/direction).

Table 23. Person 4's annual energy consumption and CO₂ production.

Urban Person 4: Commutes 5 km/day on 250 workdays by regional rail and travels 2 holiday trips to Thailand from Helsinki (7900 km/direction).					
	Annual CO ₂ generated, kg, (Train 60 % full, Long haul turbofan 100 % full)				
Annual distance travelled	Electricity	Jet A-1			
1250 km (urban)	16				
31600 km (very long dist.)		2476			
Total		2492			

Person 5: Person works as a sales representative and therefore must travel a lot between Finland's towns and cities. He travels annually 50000 kilometers by auto.

Table 24. Person 5's annual CO₂ production.

Person 5: Drives 50000 km annually by auto.					
	Annual CO ₂ generated, kg, (1 person/auto)				
Annual distance travelled	Gasoline	Diesel	Hybrid	PHEV	Gas
50000 km (highway)	7750	7200	4700	2450	5250

Person 6: Person works in an international company and therefore must travel 1820 km/direction from Helsinki to London by plane once every two weeks. Lives in Helsinki and walks or uses bicycle for daily trips.

Table 25. Person 6's annual CO₂ production.

Person 6: Commutes 1820 km/direction by airplane from Helsinki to London once every two weeks.					
	Annual CO ₂ generated, kg, (Long haul turbofan 80 % full)				
Annual distance travelled	Jet A-1				
94640 km (very long dist.)	9275				

5.3 Reasoning of results

When the results are analysed in the viewpoint of the society as a whole the most important matter to take into account are the total yearly greenhouse gas emissions and energy consumption of an individual person. As the case study of the six imaginary individuals show the individual travelling habits affect the total amount of greenhouse gases generated during a longer period of time and the single trips or the particular transport mode used on a single trip does not reveal how large the carbon footprint of an individual really is. It is the individual's total travelling habits that matter.

Making conclusions of individuals carbon footprint based only on the fact if he/she drives private car to work or if he/she uses public transportation for his/her every day trips is misleading. For example if a person makes even one very long distance trip per year it increases notably the generated greenhouse gas and energy consumption amounts. Or if a person travels weekly by air from Finland to Europe the generated greenhouse gas amounts are even more higher than with a person who travels a couple of very long holiday trips per year. The case study also shows how the everyday choices in the transport mode or vehicle type effect the annual emissions especially when travelled daily distances are long. The difference that a person drives a large gasoline vehicle or a small diesel or a hybrid has notable effects on the annual emission amounts.

It is also important to remember that the rural environment passenger travel is reliant of the private vehicles because of the distances and lack of public transport services nearby. In the other hand the existing public transport services in rural areas provided by buses have to operate even if their energy efficiency is not always as high as in private vehicles due to the small number of passenger on some routes. The bus services must provide public transportation to those who do not own a vehicle and are reliant on public transportation. The same case is in urban environment when the passenger count in public transport vehicles is low during for example night routes. The energy efficiency is not as high as during peak hours, but there must still be public transport services operating also during off peak periods.

When the focus is on the emissions of a particular geographic area the most effects are on the amounts of Particulate Matter and Carbon Monoxide which reflect directly to the

air quality near the source of emissions. Therefore, when the focus is on the air quality and emissions generated more highly localized than others, electric modes are a good choice because the emissions during electricity production are generated centralized during the electricity production near the power plant. Advantage of the electric modes is that there are no local emissions at all during the usage of the vehicle. With the use of these transport modes the air quality will not be affected during use as much as if traditional combustion engine vehicles are used. In addition the effects of the cold start which are not included in the analysis calculation increase emissions, especially the first kilometers. This increases the emissions of short distance trips when the vehicle does not have enough time to heat up. The cold start is covered more detailed in chapter 5.5. When all of the results are observed, it can be noticed that the energy consumption drops very low when fully loaded private vehicles are compared with vehicles with only the driver on board. Especially with the latest modern private vehicles that have at least two passengers, the energy efficiency and greenhouse gas generation for autos is competitive with buses in rural areas where buses carry far less people than in the urban environment. Long distance travelling by auto can also compete with buses and rail if the vehicle is fully loaded.

Especially during commuter trips in dense urban areas or during commuting to another city increasing the number of commuters/passengers in the autos reduces the traffic congestion and lowers the generated emissions and energy consumption. The increase of carpooling with help of tax concession of vehicles carrying multiple passengers or implementing congestion charges and letting carpools for free could reduce emissions and peak hour traffic congestion. The delays on peak hours could reduce and the traffic flow would be more smooth and therefore more energy efficient producing less greenhouse gases.

5.4 Other emissions

The calculation of other emissions such as particulate matter, nitrogen oxides and hydrocarbons in different situations is more complicated. The amounts differ a lot in different driving situations and the reliable comparison per passenger km is not possible.

The particulate matter (PM) emission amounts in different vehicles are usually measured in total mass which contains particulate matter in all sizes. The comparison between the total mass numbers can be misleading because the average particle size of the particulate matter emissions differs in different engine types and sizes. Also the injurious effects differ in different size particles. The smaller particles are known to be more harmful than the bigger ones (VTT 2012).

The particulate matter emissions are a problem especially for the diesel car fleet. According to the average numbers presented in the VTT's emission calculation system the particulate matter amounts are about 10 times higher for diesel vehicles compared to gasoline vehicles. The average amounts are 0,03g/km for diesel cars and 0,0035g/km for gasoline cars. For diesel buses the average particulate matter amounts are 0,19g/km which is much higher than in smaller diesel vehicles. When only the smallest particles with the most injurious effects are compared, the difference between gasoline and diesel engines is more equal. The amount of particulate matter emissions per kilometer has reduced significantly when modern diesel engines are compared to the older ones. Natural gas vehicles have no particulate emissions from the engine at all (Gasum 2012).

The different electricity production methods affect the emissions generated during the production. The 10-year average numbers indicate that the average particulate matter emission during electricity production is 0,044g/KWh (VTT 2012). The advantage of the electric modes is that there are no emissions during the usage of the vehicle and therefore also the particulate matter emissions are generated centralized in the power plants (Motiva 2012). The emissions for electric trains and while charging the PHEV which uses external electricity are generated during producing electricity. The different production methods of electricity therefore have a notable effect on the total emission amounts of the vehicle which is using the electricity.

The individual's exposure to PM emissions and also other emissions is not necessarily reliant to the transport mode which is used for the trip. According to the results presented in the article Commuters' Exposure to Particulate Matter Air Pollution Is Affected by Mode of Transport, Fuel Type, and Route, the exposures to the particulate matter emissions were highest for the passengers in diesel buses and for cyclists and pedestrians along a high traffic intensity route (Zuurbier et. al. 2010). Therefore the concentration of

emissions elsewhere out of the urban area is the best alternative to reduce exposure to the harmful emissions. Electric modes are therefore best alternatives if exposure to PM emissions is used as a reference value.

Nitrogen oxides NO_x are formed in combustion engines. The generated amount varies during different driving situations and it depends also on the engine type and the fuel used in the engine. In traffic the most nitrogen oxide emissions are generated when driving fast speeds: in urban environment the NO_x emission amounts are higher during acceleration and during highway driving when the vehicles speed is higher than in urban areas (VTT 2012).

Natural gas vehicles produce NO_x emissions but the amounts smaller compared to other combustion engines such as gasoline and diesel engines (Motiva 2012). When average natural gas buses are compared to average diesel buses the average amounts of NO_x in urban driving are for diesel urban bus 9 g/km and for natural gas urban bus 2,9 g/km (VTT 2012). The NO_x amounts in electricity production depend on the production method. When the 10 year average emission amounts presented in the VTT: s calculation system are examined, the average amount is 0,375 g/KWh.

When private vehicles using different fuel are compared the average gasoline vehicle has smaller No_x emissions than a diesel vehicle. The average amounts in year 2011 are 0,26 g/km in urban and 0,4 g/km in highway for a gasoline vehicle and respectively 0,5 g/km in urban and 0,54 g/km in highway for diesel cars. The NO_x emission amounts have lowered significantly when older cars are compared to newer models. The NO_x amounts have dropped even 95 % compared to the amounts before the introduction of the catalytic converter (VTT 2012). The decreasing of the average NO_x emissions of the private car fleet depends mostly on the new car sales and the exit of the older cars.

The amounts of Carbon monoxide (CO) and hydrocarbon (HC) emissions in vehicles have both reduced significantly when modern vehicles are compared to older cars. Road traffic still generates 73 % of the total carbon monoxide emissions and 47 % of the total hydrocarbon emissions (VTT 2012). The CO emissions are especially problem for gasoline vehicles and the generated emissions amounts depend on the driving situation. The amounts are highest when the vehicle is moving very slow or very fast or during stop-go

driving for example in urban traffic environment. The generated amounts of HC emissions are also highest during the same driving situations. For both CO and HC emissions the reduction speed depends mostly on the new vehicle sales and the exit of the older car fleet. For both HC and CO emissions the cold start of vehicles increases the emissions outstandingly (VTT 2012). The cold start problem is described in more detail in the next chapter.

For comparison according to the average emission amounts from LIPASTO emission calculation system the CO emissions for gasoline vehicles are approximately 2,0 g/km when it is only 0,13 g/km for diesels. For HC emissions the difference is smaller: for diesels the average HC emissions are 0,23 g/km and for gasoline 0,19 g/km. The numbers are average values and the actual comparison between different vehicles for different length trips is hard because the amounts vary a lot in different situations (VTT 2012).

For electric trains used in intercity and regional traffic and for the metro all of the emissions are produced during electricity production and there are no actual emissions during use. The amounts of HC, CO, NO_x and PM emissions are much lower for electric rail traffic compared to road traffic modes or airliners and the additional advantage is that the emissions are generated centralized (VR Group 2012). For air traffic the amounts of CO₂ and energy consumption during the flight can be calculated from the consumed fuel but the amount of the other emissions vary a lot during takeoff, cruising and landing. They are also dependent of the different motor types and the takeoff weight of the aircraft (Ministry of Transport and Communications 2012).

For natural gas vehicles the amounts of NO_x, CO, HC and PM are normally relatively small compared to other combustion engine vehicles. These emissions have effects on the air quality and especially the PM emissions for human health. Therefore natural gas vehicles which have almost no PM emissions at all are a good alternative especially when heavy diesel vehicles such as urban buses are replaced with gas buses. A gas engine running in great output produces approximately 20 % less CO₂ compared to an equal gasoline engine and 5-10 % less than an equal diesel engine. Nevertheless in urban environment the better efficiency of the diesel engine in low output overturns the

effects and so the CO₂ emission of natural gas and diesel buses are about the same (Motiva 2006).

5.5 Engine cold start

The cold start refers to starting the vehicles cold engine in different circumstances (winter, summer, engine heater) and driving the car as long as the engine heats up. The average driving distance for heating the engine is approximately 1-3 kilometers and it depends on the conditions. For emissions this means that additional emissions develop and the fuel consumption is higher during starting the engine and driving the first kilometers until the engine is running in its normal temperature. Starting the engine in normal summer temperatures is also a cold start even though the additional emissions are much lower than in cold winter temperatures (Auvinen et. al. 2012).

As the foregoing demonstrates the cold start and driving short distances increase the emissions especially on the first kilometers. This increases especially the emissions of short distance trips when the vehicle does not have enough time to heat up. As the trip distance increases and the engine has reached its normal running temperature the emissions soon get back to normal. According to (Auvinen et. al. 2012) over half of private vehicles in Finland are stored in some kind of shelter or under cover. Especially a warm garage lowers the cold start emissions. The problem is that especially in cities where the cars have to be parked on the side of the streets there is no possibility to use even a motor heater. In the future especially the emissions from cold starts stand out. The cold start emissions are a problem because they are developed usually near the settlement and therefore the effects are greater. Especially the hydrocarbon and particulate matter emissions will rise if there is nothing done to reduce them. Car manufacturers are coping with the problem and also with present day actions such as increasing the use of car preheaters the affects can be significantly reduced (Kalenoja et. al 2006).

6 Future

The results and conclusions of this thesis are based on the present day situation. The available motor and structural technology, popularity of different car models, population growth in different parts of the country, changes in individuals travelling habits and society and many other attributes will affect the whole travelling environment in the future. This chapter presents some speculation based on different road travel forecasts and the development of vehicle motor technology.

The population growth and especially the population's dispersion or concentration across the country has notable effects on travelling in different travel environments. According to Tiehallinto Finnish population will grow more evenly throughout the country. The population will be still growing fastest in the southern fast growing towns and cities. If the forecast is accurate the traffic volumes will develop more evenly also in rural areas. Traffic volumes are forecasted to grow up to 40 % on the main highways until 2040 and there will also be growth on the other, lower class roads although the volumes are smaller (Tiehallinto 2007). This development in rural highways will affect especially long distance travelling on peak holiday seasons when there will be much more congestion related delays and emission growth.

The motor technology and new innovations have reduced emissions steadily. For example the CO, HC and NO_x emissions of an average car in 1980 were 4-6 times bigger compared to average 2011 car models. The fuel efficiency has also been reducing steadily. For gasoline powered cars the fuel consumption has decreased 26 % and for diesel powered cars it has decreased 15 % since 1991. It has been estimated that in the future the fuel consumption will decrease approximately 1,5 % for gasoline and 1 % for diesel vehicles every year (VTT 2012). In addition to traditional combustion engines the hybrid and electric technologies have developed fast and will develop also in the future. At the moment the battery capacity is still a problem but the situation is getting better all the time. The major and most visible part of future electric engine development is going to fall upon private vehicles even though the two-wheelers and later on also heavier vehicles are also on board. In addition to normal sized private vehicles there are already few electric bicycle models available on market. The electric bicycle could be used for example in commuting and it could be an alternative for mopeds in the future. The pur-

chase prices are still relatively high (Tiehallinto 2009). The hybrid vehicles are at the moment more expensive than traditional combustion engine vehicles and they are affected by the fuel prices. Nevertheless hybrid vehicles are at the moment strongest alternative for more environmentally friendly motoring and also the PHEV vehicles are going to become more general in few years (Tiehallinto 2009).

The speed of renewing the vehicle fleet effects the emissions as the new vehicles are more energy efficient and produce fewer emissions than older vehicles. The average age for private vehicles in Finland is over 12 years and for buses 13 years as the Figure 36 below shows. The newer vehicles are driven more than older ones and therefore newer vehicles make up relatively greater share of the total traffic volume. When the older vehicles are taken out of use and especially when this development is speed up, it will reduce the private vehicle emissions in the future (Kalenoja et. al. 2006). But if the development of the car fleet continues as the statistics in Figure 44 show the cars will become older continuously.

Average age of vehicles in use 2002 - 2011

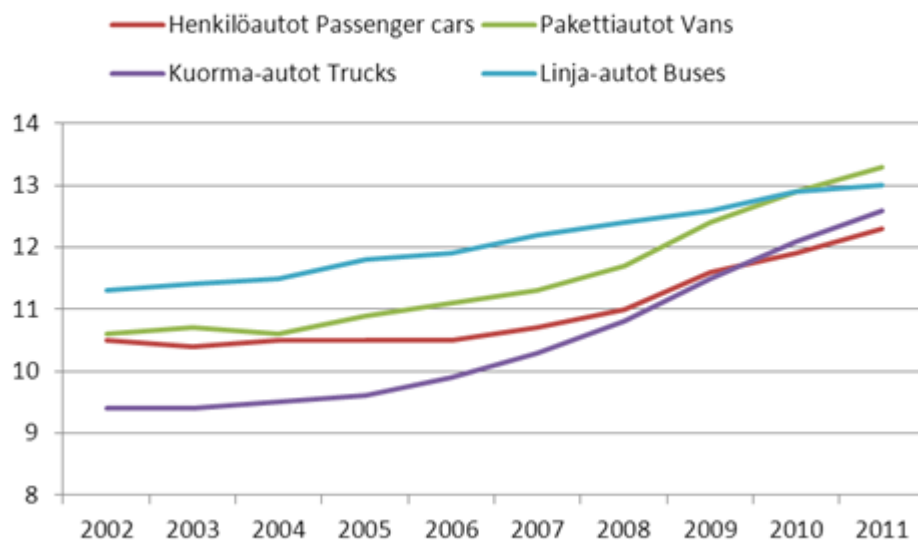


Figure 44. The average age of vehicles. (The Finnish Information Centre of Automobile Sector. 2012)

The amount of vehicle tax in Finland has been relative to the vehicles carbon dioxide emissions since 2008. The objective is to drive consumers to buy vehicles which consume less fuel and to replace older vehicles faster. The problem has been that the continuously increasing traffic volumes have reduced the effects of the improving energy efficiency of vehicles (Statistics Finland 2008).

The overall air traffic emissions are forecasted to be rising in the future due to increasing air traffic volumes. There are major differences in the air traffic volume development in different parts of the world. The fuel efficiency and energy consumption of airplanes has decreased approximately 70 % in the past 40 years. In the near future there are no alternative fuels to replace the kerosene but the energy efficiency can be improved by other technological improvements. Also the improvement of airspace use, improving the flying routes and air traffic control and flying with full airplanes will improve the energy efficiency and reduce air traffic emissions in the future. It has been forecasted that the air traffic energy efficiency is getting better approximately 1 % per year at the present level (Ministry of Transport and Communications 2012).

7 Conclusions

As the results of the thesis show there are major differences in different spatial contexts which have to be taken into account when comparing transport modes with each other. The realistic modal load factors vary and depend on the built environment, population density, time of day, and other factors. The possible choice sets of transport modes are also not the same and have obvious effects on an individual's mode choice. The relative energy efficiency and greenhouse gas generation therefore differ among the same compared modes in different situations and all of the foregoing issues affect them.

The results of this thesis are based on present traffic congestion and vehicle technology. The new car sales improve the vehicle fleet slowly but surely and the fuel consumption amounts will improve onward as well as they have improved so far. The implementation of new engine technologies such as new biofuels and new hybrid and electric vehicles will eventually make private transport modes more environmentally friendly compared to what they are at the moment. In addition the private vehicle fleet renews faster than the bus fleet which makes new motor technologies first implemented in private vehicles. This will improve their competitiveness especially against diesel buses. The more widespread use of natural gas buses in urban traffic will improve the air quality and bring down other emissions even as the CO₂ production is almost the same as in diesel buses.

Especially with the latest modern private vehicles that have at least two passengers, the energy efficiency and GHG generation for autos is competitive with buses in rural areas where buses carry far less people than in the urban environment. Long distance traveling by auto can also compete with buses and rail if the vehicle is fully loaded. Especially the hybrid and PHEV vehicles consume relatively small amounts of energy per passenger especially when there are more than two people on board. Electric trains and metro are the most energy efficient modes to be used almost in every case even though the method which was used to produce the used electricity has notable effects on the final amount of greenhouse gases or consumed energy calculated for an individual train. Cycling and walking off course are the best alternatives everywhere where they are realistic and possible to choose as modes to travel a trip.

It is important also to take into account that the private car fleet is not homogenous throughout the country or compared between dense urban and rural areas. The vehicle size, average age and performance differ. For example, newer vehicles are driven more than older vehicles. Smaller vehicles are used more in dense urban areas by reason of the limited space compared to the vehicles used in rural areas which might have to be bigger and have features to cope with the most weak conditioned forest roads. These required vehicle features set limitations and might have greater importance to consumers when buying new vehicles compared to the fuel consumption or other technical innovations.

The numbers in this thesis give information on the present situation and compare vehicles with present day load factors. The focus was to compare the modes in present day circumstances with vehicle technologies which are in use at the moment or which are soon coming to market. If the amount of private vehicles increases radically especially in dense urban areas due to the better fuel efficiency and environmentally more sustainable vehicles the advantages of the reduction of emissions and fuel consumption will be overturned quickly. There are already heavy daily traffic congestion peaks in the morning and afternoon hours as well as seasonal peaks during holidays on the rural highways. Even if the engine technology makes private vehicles more energy efficient compared to other modes the increase of the vehicles has other disadvantageous effects especially in the most populated areas. Moreover, increased space consumption has been a major byproduct of increased private vehicle usage, independent of how efficient or inefficient the average fuel consumption rate might be.

A danger of vastly reduced out-of-pocket cost of driving from this renewed fleet, particularly the PHEV, would be the physical impossibility of accommodating many more private vehicles in the existing city without changing the urban fabric and imposing huge demands for more parking and wider lanes. The public transport level of service is also affected by the increase of traffic congestion if the amount of private vehicles increases radically in dense urban areas. Nevertheless in rural areas where private vehicles are often the only realistic transport modes and the traffic congestion is not a problem, the new engine technologies make private vehicles even better alternatives to choose.

As the case study shows the completeness of individuals travelling habits is what counts. Even if the daily trips are done by modes which do not produce greenhouse gases such as walking or cycling, the annual very long holiday trips increase the total greenhouse gas generation and energy consumption radically. Of course the increasing fuel prices drive airlines to fly routes with bigger, more efficient and fully loaded airplanes which reduce the energy consumption and greenhouse gas generation of an individual person in the plane.

Furthermore, criticism of people as environmentally irresponsible citizens simply because they drive their automobile or other private vehicle is unwarranted. In rural areas, the bus exists not because it is better environmentally but because it fulfills a social need for mobility for those without autos. People who never drive in their home city may actually have the largest carbon footprint of anyone in their neighborhood if they do a large amount of long distance travel as the results show. The findings from this study argue for a more holistic and realistic approach to evaluating energy efficiency of particular individuals and in formulating policy responses.

Population growth in different parts of the country, changes in individual prosperity that will cause changes in where individuals choose to live, in an individual's vacation travelling habits and many other attributes will affect the whole travelling environment in the future. A conclusion can safely be drawn that similar results pertain and similar future changes can be realistically expected in other similarly prosperous countries.

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